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April 1963

FINAL REPORT

THE VISIBILITY OF NON-UNIFORM

TARGET-BACKGROUND COMPLEXES

H. Richard Blackwell
and
Gordon A. Bixel

409 897

THE OHIO STATE UNIVERSITY

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FINAL REPORT

THE VISIBILITY OF NON-UNIFORM TARGET-BACKGROUND COMPLEXES

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FOREWORD

ABSTRACT

Experimental studies are reported which involved measuring "detect-ion" thresholds for targets presented against pictoral backgrounds of complexly variable luminance. These studies had three principle objectives. The first was to determine the extent to which it is meaningful to assign a value of "effective contrast" to represent the visibility of a target in a target-background complex in which target and background mey be of non-uniform luminance. It was found that effective contrast is a useful concept for a given target-background complex and is generalizable to different exposure durations, probability levels, and background luminances. However, the value of effective contrast must be determined for each individual target, varying in size and luminance, when presented against a background varying complexly in luminance.

The second objective was to develop a practical device for determining the value of effective contrast of a given target-background complex. An optical device, the Visual Task Evaluator, was developed for this purpose. This instrument describes the visibility of a complex target-background complex in terms of the physical contrast of a 4 minute luminous circle having equal visibility when presented on a background of uniform luminance, measured at the visibility threshold. The validity of the Visual Task Evaluator was established by comparing its rating of 52 target-background complexes with visibility indices computed from physical contrast values and visibility threshold data.

The final objective involved a study of the luminance characteristics of target-background complexes affecting their visibility. Three non-uniform backgrounds were used, with targets varying in size, luminance, and placement within the non-uniform backgrounds. Two backgrounds were stylized whereas the third was a terrain photograph. The general principal was found that, when the background luminance varied within the area occupied by the target, it was the target contrast with the luminance at its border which determined target visibility.

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I. INTRODUCTION

The present is the third and final report in a series concerned with studies of the visibility of targets presented in target-background complexes of non-uniform luminance. What is considered the useful material from all the experiments is summarized here so that the reader need not refer to the earlier reports. The experiments have covered a variety of topics first and last, but it will be possible here to show the systematic nature of the developments and execution of the research program. It may be stated at the outset that the experiments have been found very difficult to conduct due to precision limitations which appear fundamental to the scientific problem.

The basic philosophy of the present experiments can be said to be the logical extension of an approach taken by one of us for a number of years. It was first in 1946 that Blackwell (Ref.1) demonstrated the significance of specifying the contrast of targets as an invariant index of their visibility. A definition of target contrast was proposed which was intended to have equivalent significance for targets which were either brighter or darker than their background. This definition is as follows:

$$C = \frac{B_t - B}{B} \tag{1}$$

Where B_t is target luminance; and
B is background luminance.

It was demonstrated that for simple targets of uniform luminance viewed against backgrounds of uniform luminance, targets of equal contrast brighter and darker than their background were equal in detectability. It is customary to refer to targets brighter than their background as having positive contrast, whereas targets darker than the background are considered to have negative contrast. Usually, the algebraic sign of the value of C is ignored and the visibility expressed in terms of the logarithmic value of C taken without regard to sign.

Preliminary experiments were conducted during these early studies

utilizing targets of non-uniform luminance viewed against backgrounds of uniform luminance. These targets consisted of light and shadow patterns which resulted in some areas being brighter, others darker than the background. Sufficient studies were conducted (Ref.2) to indicate some of the problems involved in the detectability of targets of non-uniform luminance. It was found, for example, that when a target of mixed contrast was viewed at sufficiently small angular subtense, the positive and negative contrast areas tended to cancel one another and the target was difficult if not impossible to detect. When the same target was viewed at larger angular subtense, however, the individual positive and negative contrast areas tended to accentuate one another. This result suggests that we have to consider the resolved contrast as it were rather than the physical contrast of a target. These results must signify that the effect of the angular size of targets of non-uniform luminance is more exaggerated than was the case with targets of uniform luminance. Thus, a target of mixed contrast may be equal in detectability to one simple uniform target when both are viewed from one distance, and equal to a uniform target of different size when both are viewed from a second distance.

Some years later, Gordon and Lee (Ref.3) conducted an empirical study of the detectability of simulated three-dimensional military targets viewed against simulated terrain backgrounds. The targets and backgrounds consisted of complex light and shadow patterns. Detection thresholds were obtained by moving the observers toward the targets until the targets were reported to be just detectable. Analysis of the data led Gordon and Blackwell (unpublished) to postulate that one important variable in addition to the contrast values of various target areas was the size of major light and shadow patterns in the target in relation to the distribution of size of light and shadow patterns present in the background. On the basis of this hypothesis, an experiment was conducted in which simple circular targets of varying sizes were placed in a

uniformly textured background field. For each of four physical sizes of target, the angular size was determined at which the target was just detectable against the same textured background. It was found, as expected from the earlier analysis, that the circular targets were least detectable (had to be of largest angular subtense) when their physical size was approximately equal to the size of the light and shadow patterns of the background. These results suggest that backgrounds of non-uniform luminance may have a noise-masking effect which will be different for targets of different sizes.

Subsequently, Hamilton (Ref.4) studied three-dimensional simulated military targets viewed against simulated terrain backgrounds. This investigator attempted to obtain detection probability data for these complex target conditions. He utilized a psychophysical method of constant stimuli, involving a "Yes - No" response. Analysis was made of four classes of responses: (a) "Yes," with the target actually present; (b) "No," with the target actually absent; (c) "Yes," with the target actually absent; and (d) "No," with the target actually present. The data clearly revealed that for target and background complexes of non-uniform luminance, idiosyncratic relations exist among the four categories of response which invalidate the usual analysis of psychophysical data collected with this method. Indeed, there was no obviously satisfactory analysis method for use with these data. This result suggests that a psychophysical response which can be interpreted without ambiguity must be used in studying target-background complexes of non-uniform luminance. It also calls attention to the possible difficulty of correctly interpreting the decision process involved in detection when targets and backgrounds are of non-uniform luminance.

Somewhat more recently Harcum (Ref.5) has studied detection and recognition thresholds for simplified targets of non-uniform luminance imbedded in backgrounds of similar luminance non-uniformity. Targets and backgrounds were constructed from matrices of light and dark squares. The dependency relationships

of adjacent elements of the matrices used in constructing the targets and the backgrounds were varied systematically and the relation of this variable to target detectability was found. These results probably do not refer to detection as the term is usually used, since a rather high degree of spatial organization was required for differentiation of target from background even under the most simplified conditions.

It seems apparent from the various studies reported above that much empirical and theoretical work will be required before we have even a reasonably complete understanding of the visibility of targets in target-background complexes of non-uniform luminance. We may expect to have to deal with the problem of resolved versus physical contrast, the problem of the noise-masking effect produced by a non-uniform background, and the nature of the decision process implied by the framework of the experiment. As Blackwell has suggested recently (Ref.6), the detection problem must undoubtedly be conceived in terms of the neural correlates of stimuli rather than in terms of the stimuli themselves, and we may deduce a number of the probable characteristics about the neural correlates of such stimulus parameters as intensity, size and exposure duration from experiments involving targets and backgrounds of uniform luminance.

The notion as formulated by Kincaid, Blackwell and Kristofferson (Ref.7) is that each point in the stimulus domain is "mapped" into an area in the neural domain with variable intensity existing from point to point. This formulation represents a further development of an idea originally suggested by Graham, Brown, and Mote (Ref.8). It has been shown to have descriptive value for targets of uniform luminance under various experimental conditions by Kristofferson and Blackwell (Ref.9); Blackwell and Smith (Ref.10); and Smith, Blackwell and Cutchshaw (Ref.11). It also has some descriptive value for simple targets of non-uniform luminance viewed on backgrounds of uniform luminance, as shown by Kristofferson and Dember (Ref.12), and Kristofferson and O'Connell (Ref.13).

It has also been suggested (Ref.14) that there is a temporal mapping of stimulus effects in the neural domain, although this aspect of what may well be the kind of general theory which is required is of less direct interest in connection with the present series of experiments.

It should be apparent that the neural correlate of a target-background display of completely variable luminance would be difficult to compute or even to conceive. Further, even if such a transformation would be carried out, the problem of determining the detection criterion would remain. For these reasons, it seems acceptable and even necessary to study this complex detection problem at a less sophisticated level than is suggested by the above description of the problem. We have explored the feasibility of taking an experimental short-cut which may enable us to deal with the visibility of targets in target-background complexes at a useful empirical level. The basic idea is that a value of "effective contrast" may be assigned a target in a target-background complex of non-uniform luminance which will have analogous properties to the values of physical contrast usually assigned to targets in simple target-background displays of uniform luminance. This means that a value of effective contrast will indicate the level of visibility of the target faithfully, in comparison with a value of physical contrast applied to a target in the simple case. If it can be shown that it is meaningful to assign a value of effective contrast in this sense in dealing with the target-background complexes, presumably use can be made of our rather extensive knowledge of the visibility of simple targets.

In accordance with this idea, considerable research effort has been devoted to a study of the extent to which the notion of effective contrast is useful. The focus of interest has been a study of the extent to which a value of effective contrast assigned in an arbitrary manner under one set of conditions properly describes the visibility of a target-background complex under other conditions. What is meant precisely by "properly describing the visibility" is

that a target-background complex changes in visibility when expressed in terms of a scale of effective contrast in the same quantitative way in which a uniform target changes in visibility when expressed in terms of a scale of physical contrast. Looked at another way, this means that a uniform target and a target-background complex which are equal in visibility under one condition should be equal in visibility under other conditions. Conditions which should affect the uniform target and the target-background complex equally would include variations in adaptation level, small variations in contrast or effective contrast which would alter the probability of detection, variations in exposure time, and variations in angular size. We have tested the extent to which a value of effective contrast assigned in an arbitrary manner is generalizable across these very conditions.

We have also developed an optical comparator to be used in assigning values of effective contrast to target-background complexes, and have validated it by assessing to what extent the values of effective contrast so obtained agree with expectations based upon physical measurements and published data relating visibility to the measured physical parameters.

Finally, we have studied the luminance characteristics of targets and their backgrounds to determine the effect of these variables upon visibility of the target-background complexes. This study has been descriptive rather than theoretical.

Three different equipment set-ups have been used. The first was relatively crude and necessitated that visibility thresholds be measured by the method of adjustment. The other two were much more elaborate and permitted use of the method of contrast stimulus. The first of the more elaborate set-ups involved the use of photographic transparencies for the target-background complexes. Use of this stimulus material limited the experiment in undesirable ways. Accordingly, we rebuilt the equipment to permit us to view realistic

target-background complexes directly, which increased the flexibility of our equipment.

The apparatus, procedures and results obtained in our various experiments will be reported in a more-or-less chronological order, with indications being given of the hypotheses held at various times during the program. Finally, the results of all the studies will be brought together in summary fashion and our recommendations for future research will be presented for what they are worth.

II. STUDIES OF THE GENERALIZABILITY OF VALUES OF EFFECTIVE CONTRAST.

A. Effective Contrast at Different Adaptation Luminances.

Studies of effective contrast for target-background complexes at different adaptation luminances have been made with a method of adjustment procedure. Although lacking somewhat in precision, the method of adjustment procedure had the advantage that measurements could be made rapidly without delay involved in the development of highly complex equipment.

1. Apparatus and Procedures.

A number of target-background complexes were developed based upon a standard background of non-uniform luminance, constructed from more than 2,300 one-half inch ball-bearings. The bearings were mounted in a square plate, measuring 24 inches on a side. A layer of hot wax was poured into the plate and the bearings were arrayed in the wax before it hardened. Then, layers of gray paint were sprayed over the bearings and the spaces between to create a regular pattern of non-uniform luminance. The ball-bearing board was mounted in an upright position at the end of a long tunnel.

Translucent nylon threads were stretched diagonally across the ball-bearing board, crossing in the exact center. Paper targets were glued onto the junction of the nylon threads. This procedure insured that the paper targets did not damage the paint on the ball-bearings. Two classes of targets were utilized, circles and rectangles. The circles had diameters of .25, .5, 1.5, 6 and 12 inches. The rectangles had dimensions of .25 x 5, .5 x 5, 1 x 5, 3 x 5, and 5 x 5 inches. Each target was prepared both with white and with black paper so that the targets appeared both brighter and darker than the background. The 1.5 inch bright target and ball-bearing board background are shown in Figure 1. Note that it is not possible to detect the presence of the nylon threads used to support the paper target. The luminance of each target-background complex was varied by adjusting the

illumination falling on it from a 35 millimeter slide projector, fitted with a holder to accommodate 2 by 2 inch glass-mounted Wratten neutral filters.

Studying the generalizability of the effective contrast of a target-backgound complex requires that measurements be made with simple target-background displays in which the luminances of the targets and background are uniform for purposes of comparison. A uniform gray plate was produced of the same size as the ball-bearing plate. White and black paper targets were mounted in front of the gray board. All the targets used with the ball-bearing board were used also with the uniform gray board.

The generalizability of effective contrast for target-background complexes at different adaptation luminances was studied by determining the visibility threshold for these complexes and for uniform background displays at different luminance levels. The basic idea is that a value of effective contrast is in fact constant at different luminances if the visibility threshold expressed in terms of a scale of effective contrast changes in direct proportion to the change in threshold contrast of a uniform target-background display at the same luminance levels. This idea will be more easily comprehended when we examine the results of our study.

Visibility thresholds were determined by a method of adjustment involving reduction of the contrast of the entire target-background display, whether the background was of uniform or non-uniform luminance. This was accomplished with equipment represented schematically in Figure 2. The basic principle of the device is that a veil of uniform luminance is superimposed over the observer's view of the target-background display, and increased in luminance until the presence of the target can just barely be detected.

The detailed operation of the device may be described as follows: the operator views the stimulus material through a unit power telescopic system consisting of an objective lens and an ocular (lens L1). The view of the

stimulus material appears in the inner circular field of a photometric cube, which has an angular extent of about 5 degrees. The luminance of the stimulus material is represented by the symbol, B_s, in the figure. The light veil, B_v, is produced by a lamp and collimator (lens L2) and is added to the circular inner field of the photometric cube. Thus, the beam represented by the dark arrowheads represents one or both of the beams B_s and B_v. Now, the "variable contrast wedge" identified in the figure is in reality a variable transmittance - variable reflectance wedge, for which the sum of reflectance and transmittance is approximately constant. This wedge was produced for us by D.M. Finch of the University of California at Berkeley. It was prepared by evaporating a different thickness of a metallic coating at each point around the circumference of a clear glass disc. As the wedge is rotated about an axis perpendicular to its surface, the reflectances and transmittances change so as to alter the relative amounts of B_s transmitted and of B_v reflected. As noted, the product of the transmittance and the reflectance values is approximately constant at all positions of the wedge.

Now, the contrast of the target in the case of a background of uniform luminance may be written

$$C = \frac{B_t - B_s}{B_s} \qquad (1a)$$

The variable contrast wedge alters the contrast to a new value, C', which may be written

$$C' = \frac{(B_t - B_s) T}{B_s T + B_v R} \qquad (2)$$

where T equals the transmittance of the variable
contrast wedge; and
R equals its reflectance.

We may define CR, the "contrast rendition" of the variable contrast wedge as follows:

$$CR = C'/C = \frac{B_s T}{B_s T + B_v R} \qquad (3)$$

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In the special case where $B_s = B_v$

$$CR = \frac{T}{T + R} \tag{3a}$$

Thus, CR is a function of the portion of the wedge inserted in the optical beam and is independent of the precise values of B_s and B_v so long as $B_s = B_v$.

The values of CR for various portions of the wedge were established by physical measurements of the values of T and R. A photomultiplier photometer designed by our late colleague, B.S. Pritchard*, was utilized with a telescopic system used to narrow the acceptance cone of the photometer to a 2 degree cone.

In order to utilize these data, it is necessary to insure that during use of the device, the value of B_v equals the value of B_s. A luminance equation is made between B_s and B_v by means of the introduction of a third luminance, B_a. The quantity B_a equals the luminance of an annulus in the photometric cube which surrounds the circular inner field. It will be remembered that the inner field can be illuminated by B_s alone, by B_v alone, or by any desired combination of these two quantities, depending on the position of the variable contrast wedge. The luminance of the annulus is adjusted by rotation of the "variable absorption wedge" identified in the figure until the annulus matches B_s. This wedge consists of a continuously variable density of Wratten neutral filter material located around the circumference of a circular disc. Rotation of the wedge along an axis perpendicular to its surface produces a variable transmittance and hence a variable value of B_a. The transmittances and reflectances of the beam-splitters BS1 and BS2 are adjusted so that $B_a = B_v$; this equation is valid for all positions of the variable absorption wedge. Thus, when $B_a = B_s$, it is also true that $B_v = B_s$.

When the stimulus material involved the uniform gray board, the inner field of the photometric cube was uniform in luminance and the equation between

*Marketed as the Spectra Pritchard Photometer by the Photo Research Corporation, 837 North Cahuenga Blvd., Hollywood 38, California.

B_a and B_s could be precisely established. However, when the stimulus material involved the non-uniform ball-bearing board, the inner field of the photometric cube was non-uniform in luminance and the equation between B_a and B_s was difficult to make. In order to improve the precision of this match, a second objective lens was substituted for the original objective lens, which formed an image of the stimulus material in the plane of the pupil of the observer's eye. The portion of the optical beam conjugate with the observer's retina is uniform in luminance under these conditions. It is as though we took the light flux from the entire 5 degrees of the non-uniform background and redistributed it uniformly to aid the observer in equating B_a and B_s in luminance. Although either object-ive lens could be used with the background of uniform luminance, for consistency the second objective lens was always used when the equation was made between B_a and B_s.

We may now summarize the experimental procedure as follows: First, the second (blurring) objective lens is inserted and a luminance equation is made between B_a and B_s by adjustment of the variable absorption wedge. The stimulus material for this procedure is the background alone, be it the uniform gray board or the non-uniform ball-bearing board. Next, the original (imaging) object-ive lens is inserted and the target is inserted in front of the background. Then, the variable contrast wedge is adjusted until the target is just barely visible. The wedge position is read off and the value of CR obtained from the physical measurements made previously. Values of CR were obtained for the various targets viewed against both uniform and the non-uniform backgrounds.

For a uniform target-background display, the threshold contrast

$$\bar{C} = C \times CR \qquad (4)$$

For a target-background complex, the effective threshold contrast

$$\bar{C}_e = C_e \times CR \qquad (4a)$$

Where C_e equals an arbitrary measure of the effective
contrast of the target-background complex.

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We chose merely for reasons of convenience to specify C_e as follows:

$$C_e = \frac{B_t - \bar{B}}{\bar{B}} \qquad (5)$$

where $\bar{B}$ is the average luminance of the ball-
bearing board.

There was not considered any necessary reason why the value of C_e should be equal

to the value of C for the same size target, although our gray board did in fact

have very nearly the value of $\bar{B}$ of the ball-bearing board. Neither did we have

any reason to expect values of $\bar{C}$ and $\bar{C}_e$ to be equal. The basic test of the

generalizability of a value of effective contrast assigned to a target-background

complex is the extent to which the values of $\bar{C}$ and $\bar{C}_e$ change proportionally as

luminance is altered.

To proceed in this way, we began by making physical measurements of the

luminance of each target when presented against the uniform background, and the

luminance of the background as well. The values of C were computed from equation

(1a). These measurements were made at each luminance level to be studied so

that any slight changes in actual contrast due to inadvertent changes in the

geometry of illuminating the target-background display would be taken into

account. We made the measurements with the photomultiplier photometer described

above. We then measured values of $\bar{B}$ by having the photometer integrate light

flux from the 5 degree area of the ball-bearing board. Values of C_e were

computed from this value and the values of target luminance from equation (5).

Values of $\bar{C}$ and $\bar{C}_e$ were computed from values of C and C_e together with the values

of CR when the optical device was set for the visibility threshold. The levels

of adaptation luminance were taken as the values of B_s for the uniform back-

ground and $\bar{B}$ for the ball-bearing board background.

Three series of experiments were conducted. The distance from which

the ball-bearing plate was viewed varied among experiments so that the angular

size of each element of non-uniform luminance was an experimental variable. In

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addition, the angular size and shape of the target varied among experiments. All measurements were made by a single skilled observer. Each experimental datum involved a single careful setting of the variable contrast wedge. The setting of the value of B_a to equal B_e was made carefully once for each background luminance and with each class of target.

In the first series of experiments, the viewing distance was 46.6 feet so that each element in the ball-bearing board subtended 3.08 minutes of arc. Five circular targets were studied with diameters both smaller and larger than each background element, since earlier work (Ref.3) had suggested that the relative size of the target and the elements of non-uniformity in the background should influence target visibility in an important manner. The diameters of the circular targets were 1.54, 3.08, 9.23, 36.9, and 73.8 minutes.

2. Results.

Values of $\overline{C}$ and $\overline{C}_e$ are presented for these five classes of targets in Figures 3-7. In each case, open circles refer to bright targets and filled circles refer to dark targets.

Values of $\log \overline{C}$ and $\log \overline{C}_e$ are displayed separately in each figure for: (a) uniform backgrounds, with targets both darker and brighter than the background; (b) non-uniform backgrounds, with targets brighter than the background; and (c) non-uniform backgrounds, with targets darker than the background. In order to display the three sets of data properly, values have been arbitrarily displaced upward along the logarithmic ordinate, which has been labeled "log relative $\overline{C}$" to reflect the arbitrariness of the absolute values plotted.

The basic data analysis consisted of fitting a smooth curve through the data relating log relative $\overline{C}$ to log B for the uniform background case and then testing the extent to which this curve could be fitted to the data relating log relative $\overline{C}$ to log $\overline{B}$ for the non-uniform background case, when the curve was adjusted along the scale of log relative $\overline{C}$ to provide the best fit. If the

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curve fitted through the data for the non-uniform background was adequate to describe the data, we considered that the effective contrast of the target-background complex was the same at all values of luminance. This conclusion may be derived from our definitions of $\overline{C}$ and $\overline{C}_e$ in equations (4) and (4a).

The solid lines in Figures 3-7 were fitted through the data for bright and dark targets presented on uniform backgrounds, utilizing the more numerous data of Blackwell and McCready (Ref.15) for guidance in the determination of the curve form. Data for bright and dark targets agree in general. If anything, the thresholds are lower for large dark targets at the lower luminance levels, just as Blackwell (Ref.1) reported in 1946. The dashed lines represent the adjustment of this curve upward along the scale of log relative $\overline{C}$ to best fit separately the data for the bright and dark targets presented against the ball-bearing board.

Examination of the data in Figures 3-7 reveals fair adherence of the points to the sets of dashed curves. Although the precision leaves much to be desired, the agreement of the points to each dashed curve is almost as good as the agreement of the points obtained with the uniform backgrounds to their solid curves.

(It may be pointed out that, to a very close approximation, values of log CR could have been used in plotting Figures 3-7 without changing the appearance of the graphs. This results from the fact that neither values of C nor C_e change appreciably as B_8 or $\overline{B}$ are changed since contrast values depend almost solely upon the reflectances of the background and target materials. The values of C and C_e do change a little with B_8 and $\overline{B}$ due to stray light, so that it is somewhat more accurate to use values of $\overline{C}$ and $\overline{C}_e$ than values of CR. This point is worth making since it emphasizes the insignificance of the arbitrary definition used for C_e).

The second series of experiments were conducted with a viewing distance of 17.9 feet, so that each element in the ball-bearing board subtended 8.00

minutes. Data for circular targets subtending 4, 8, and 24 minutes are presented in Figures 8-10. Data are available for five rectangular targets subtending 4 x 80, 8 x 80, 16 x 80, 48 x 80, and 80 x 80 minutes and are presented in Figures 11-15. The method of data analysis is the same as before and the conclusions are the same. It appears that the data obtained with target-background complexes of non-uniform luminance are in general adequately fitted by curves derived from data on uniform backgrounds. Hence, the value of effective contrast assigned to each target-background complex may be considered to remain constant for all the luminance levels studied.

In the earlier report of these data (Ref.16), the data for bright and dark targets presented against the ball-bearing board background were plotted in terms of $\bar{C}_e$ and a single curve was fitted through them derived from the data for uniform backgrounds. Plotting the data for bright and dark targets in this way is equivalent to assuming that the definition of C_e given in equation (5) is meaningful for the two types of targets. In the earlier report, it was noted that the data for bright and dark targets were somewhat different from one another. This presumably signifies that the values of effective contrast for the two classes of targets cannot be defined by equation (5). As we shall see, the use of the average luminance, $\bar{B}$, to define C_e does not properly define effective contrast for bright and dark targets. Thus, the procedure used in the earlier report introduced unnecessary error into the evaluation of the generalizability of effective contrast for values for different targets to different levels of adaptation luminance, and the present analysis is distinctly preferable.

In view of this remark, it is especially interesting to recall that the numerical values of $\bar{C}$ and $\bar{C}_e$ were compared in the earlier report in terms of a

coefficient ρ where

$$\rho = \frac{\overline{C}_e}{\overline{C}} \qquad (6)$$

in our present notation. The value of ρ was shown to equal very nearly unity, which signifies that $\overline{C}_e = \overline{C}$ and that therefore C_e must represent the correct definition of effective contrast for the target-background complexes. As we shall see, this conclusion is in fact incorrect when all data are taken into account, and the fact that the values of ρ equalled so nearly unity was only a coincidence. Of such stuff is scientific confusion bred!

B. Effective Contrast at Different Probability Levels

The studies of effective contrast for target-background complexes at different probability levels have been made utilizing a method of constant stimulus procedure. Rather elaborate equipment and procedures were developed for this purpose which will be described in some detail since they are believed to represent new advances in methodology for studies of complex visual displays involving targets and backgrounds of non-uniform luminance.

1. Apparatus and Procedures

The method of constant stimulus requires that each of a number of "stimuli", varying in difficulty, can be presented repeatedly and the probability of some discriminatory response determined for each stimulus value. In the present problem the difficulty of the stimulus material, consisting of a different target-background complex in each experiment, was altered by super-imposing some particular amount of veiling luminance over the entire complex. As in the experimental procedure described in connection with our studies using the method of adjustment to threshold, the overall luminance of the target-background complex was maintained constant by reducing the light coming from the stimulus material in direct proportion to the amount of light veil added to reduce overall contrast.

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The discriminatory problem presented to the observer was to identify which one of four temporal intervals in a sequence contained a target-background complex, the other three containing the same background complex without the target. The forced-choice method of Blackwell (Ref.17) was utilized since this method has been shown (Ref.18) to possess greater validity and reliability than the more usual method involving direct subjective appraisal of the presence or absence of discrimination. The use of the best possible methodology is of particular importance in the present problem, since the judgment that a target can be just seen in a target-background complex is not a simple one for an observer to make.

The major problem with the forced-choice method is that the observer can discriminate the target from the non-target on any basis available to him. In order for the data to be meaningful, the experimenter must be assured that the observer is making his discriminations on a basis known to the experimenter and intended by him to be the experimental variable. Eliminating all differences between the target-background complex and the background alone except the presence or absence of the target is a formidable undertaking. This problem was anticipated in our original design of the procedure for this experiment. Accordingly, it was arranged that the target and non-target presentations not be presented in temporal contiguity. Instead, target and non-target presentations were separated by "neutral intervals" in which a uniform field was presented. As we shall see, the problem of eliminating all differences between target and non-target presentations except rhe presence or absence of the target was formidable even with this arrangement.

The experiments were conducted in a room 12 ft. wide, 12 ft. long, and 8 ft. high. This room was divided by a wall into two portions with the observer on one side, and the apparatus on the other. A schematic drawing of the experimental set-up is shown in Figure 16. The observer sat on one side of the wall

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in relative darkness. He was faced with a white uniform surround measuring 11 by 14 inches and located 9.75 inches from his eye. Thus, the surround subtended more than 60° in each direction. The surround was illuminated by four lights on the side of the wall opposite from the observer's station, located at a radial distance of 6 inches from the center of the wall. The luminance of the surround was about 450 foot-lamberts. In the center of this surround there was a 13/16 inch diameter round hole covered from behind by a shutter of the same white material as the surround. Opening this shutter exposed a real image of the stimulus material, located in the same plane as the surround. The image of the stimulus material subtended about 5°. The outer circumference of the stimulus was masked by an out-of-focus aperture which created a blurred border slightly smaller than the 13/16 inch hole in the surround.

A solenoid-operated shutter created the following presentation cycle: (a) a 3.4 second period between a warning buzzer and the beginning of the first presentation interval; (b) four 1.9 second presentation intervals, separated by 1.0 second neutral intervals; and (c) a 6.0 second period for data recording.

During three of the four presentation intervals, the background complex was exposed. The target-background complex was presented during one of the four presentation intervals selected at random, and the observer was asked to select which of the four presentations contained the target. In case no target was seen, the observer was asked to select and record the one of the four most likely to have contained the target. The observer recorded his selection by depressing one of four buttons mounted near his hand, which recorded correct or incorrect answers on suitable electric counters.

The stimulus materials were photographic transparencies which were alternately exposed to the observer's view. The original targets were matte white or black circles of .25, .5, and 1.5 inch diameters. They were photographed centrally positioned against two different backgrounds: the 2 foot

square uniform gray and ball-bearing board backgrounds described in connection with the method of adjustment experiments. Photographs were also made of the two backgrounds without a target. Glass positive transparencies were prepared.

Separate light paths were used for (1) the transparency of the target-background complex and (2) the transparency of the background complex only, as shown in Figure 16. The two transparencies were illuminated by lamp La2 through beams separated by beam-splitter BS4. The two beams were made to coincide by beam splitter BS3. Shutter 2 had two flags, one of which covered each beam. The flags operated in what might be called a "wig-wag" fashion, in which rocking of the dual shutter about a pivot alternatively covered one beam and uncovered the other, or vice versa. Lenses L3 and L1 formed an image of either transparency in the plane of the surround, located 9.75 inches from the observer's eye. Illumination for these transparencies was provided by a Maxwellian system. The image of the source in lamp La2 was placed by lens L4 or alternately L5 in the plane of lens L3. The image in turn was placed by lens L1 in the plane of the pupil of the observer's eye. The plane of the surround was conjugate with the observer's retina so that he obtained an in-focus view of the transparencies.

The operation of the wig-wag shutter thus provided us with what we might call an optical substitution system in which the target-background complex could be substituted for the background complex at will. This type system is required for the presentation of stimulus material involving patterns of non-uniform luminance for use with a forced-choice psychophysical method.

This system required very careful adjustment of the paired transparencies and their light paths to avoid the introduction of extraneous cues. The adjustment criteria may be listed as follows:

a. The two paired transparencies must be identical except for the target. Dust particles from the developing process, scratches, uneven development, etc. must be eliminated.

b. The light paths through the paired transparencies must be of equal intensity.

c. The two paired transparencies must appear of equal size.

d. The vertical and horizontal positioning of the two transparencies must be sufficiently accurate to eliminate visible differences in alignment.

The last two criteria mentioned above were critical in the case of the non-uniform background. The blurred outer border created by the aperture previously mentioned was used to prevent the observer from aligning some of the balls in the non-uniform background with the edge of the hole in the surround, which could have provided a very sensitive extraneous cue for making the correct interval choice corresponding to the target condition.

The possibility of so many extraneous cues suggested the need for a means of insuring that these cues were not being used by the observer to aid in his detection of the target. Accordingly, a masking plate was made up consisting of a small black dot on a clear glass plate which was placed in the plane of the surround in such a position that it covered the target when the transparency with the target was presented. If the observer was unable to get more than a chance number of correct answers with the masking plate in place, the conditions were deemed adequate and the experiment proceeded. A masking-plate control run was made with each observer for each pair of transparencies at the beginning and end of each experimental session.

Reduction in contrast was accomplished by adding veiling light and reducing the light from the stimulus material so that the combined light intensity from the two remained constant. There were two separate systems for adding veiling light and reducing stimulus intensity, the "wheel filters" and the fixed filters.

a. The wheel filters

Veiling beam SV from lamp Lal in the top center of Figure 16 traveled through filter wheel 2 and filter holder F4. The wheel contained five separate

filters, any one of which could be placed in the light path by manipulation of a control switch which rotated the wheel into the desired position. The relative transmittances of the filters were as follows:

Position 1-45%;   2-56%;   3-65%;   4-87%;   5-100%

This veiling light was added to the beam seen by the observer by means of beam-splitter BS2.

Filter wheel 1 reduced the intensity of the stimulus material. Its filters had the following relative transparencies:

Position 1-100%   2-88%;   3-70%;   4-51%;   5-45%

Filter wheels 1 and 2 were mechanically linked so that a position of one always implied a given position of the other, e.g. position 1 allowed the maximum light through from the stimulus material and a minimum of veiling light, while position 5 allowed the minimum light from the stimulus material and a maximum veiling light. These two filter wheels were so balanced that the resultant total light intensity remained approximately constant. The source in lamp Lal was imaged about 2 inches behind (right of) the plane of the surround. While this was not a true Maxwellian system, it was quite adequate to provide the necessary intensity and uniformity of illumination of veiling light.

b. The fixed filters

The other source of veiling light (labeled V in the diagram) comes through filter holder F3 and was added to the main beam by beam-splitter BS1. The V beam formed an image of lamp Lal about 2 inches in front of the observer's eye. Though this was also not a true Maxwellian system, it was adequate to provide the necessary intensity and uniformity of illumination of veiling light. The contrast of the stimulus material was reduced by adding filters to holder F1 while at the same time removing filters from F3 such that the total light intensity remained constant. This was the method used to adjust the contrast to the threshold range of each observer for each target-background complex, and these

filters were not changed until the observer had completed all the runs on that target. The contrast was varied within the threshold range by means of the filter wheels mentioned above.

The filter holders F2, F4, F6 and F7 were used to balance the light intensities from the various beams. Glass plates were inserted in F6 or F7 to equalize any small overall difference in transmittance between the pair of transparencies. This balance was made carefully for each target. Filters were put in holder F4 to equate the intensity of veiling beam SV with the intensity of the beam containing the stimulus material. For this balance, the filter wheels were put in the position of maximum transmission. Filters were used in holder F2 to equate the intensity of veiling beam V with the total of the SV beam and the beam containing the stimulus material.

The filters in holders F2 and F4 remained the same for any series of targets of approximately equal transmittance. The beams were rebalanced with a different set of filters when a series of targets with a different overall transmittance were used.

In addition to these two methods designed specifically for reducing contrast, there was some loss of contrast due to scatter in the various lenses. This effect was carefully measured and the contrast values were corrected accordingly.

Two observers were used.

a. RC: a 26 year old white male with an ophthalmic correction for distance as follows:

OD   -.75   -.25 x 180

OS   -.75   -.25 x 135

RC did not wear this correction during the experiment.

b. DH: a 49 year old white female with an ophthalmic correction for distance as follows:

OD -.50 -.75 x 80

OS -.50 -.25 x 90

DH did not wear this correction during the experiment but used a +3 diopter lens to assist accommodation.

Adequate motivation seemed to be present despite the considerable tedium of long observing sessions.

The overall dimension of the target plate was known to be 2 ft. In the slide it was measured by a toolmaker's comparator. The reduction in size of the overall dimension of the background plate was used to establish the demagnification produced in photography, and the size of the target in the slide was computed on this basis. The target diameter thus found was multiplied by a magnification factor of 1.327 introduced by the optics in the optical substitution apparatus and the resultant image size converted to minutes of arc for each target. These were 4, 8, and 24 minutes for the .25, .5 and 1.5 inch targets respectively.

The values of C and C_e for the targets presented against uniform and non-uniform backgrounds were defined in terms of equations (1a) and (5) as before. The values of C_e thus correspond to considering the average luminance of the non-uniform background as the background for the targets. The values of C and C_e actually presented to the observers by slides viewed through the optical substitution apparatus are products of the physical contrasts in the slide and the contrast rendition introduced by the device. Our calculations of the contrast values for the targets with uniform and non-uniform backgrounds were complex and laborious and may be described as follows:

a. Contrast of the target transparencies. The contrast of each target compared to its background was measured by a special densitometer arrangement which allowed accurate measurements of even the smallest targets. This was

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accomplished by projecting an enlarged image of the target and its background on to a photomultiplier densitometer. Stray light was reduced by masking all but a small portion of the target plate and darkening the room. Forty background measurements were made and averaged for targets with the uniform background, and fifty were made for the non-uniform backgrounds. The contrasts of two of the larger targets were also measured in situ in the optical substitution apparatus by means of the photomultiplier photometer described earlier. The loss in contrast due to stray light in the optical substitution apparatus was shown by this method to be 7.8%. A correction for the stray light effect was made for each target transparency.

b. Contrast rendition of the filter wheels. The transmittances of the filters in the five wheel positions have been given previously.

Contrast rendition was computed by the formula:

$$CR = \frac{S}{S + SV} \tag{7}$$

where S = relative intensity of the beam containing the stimulus material as modified by filters in filter wheel 1; and
SV = relative intensity of the SV beam as modified by filters in filter wheel 2;

The contrast rendition values were as follows:

Wheel Position	Contrast Rendition
1	.690
2	.610
3	.518
4	.368
5	.310

c. Contrast rendition of filters in holders F1 and F3. Contrast rendition was computed by the formula:

$$CR = \frac{S + SV}{S + SV + V} \tag{8}$$

where S = relative intensity of the beam containing the stimulus material as modified by filters in filter holder F1 for wheel filter position 1;

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SV = relative intensity of the SV beam as modified
   by filters in filter holder F1 for wheel filter
   position 1; and
V = relative intensity of the V beam as modified by
   filters in filter holder F3

The luminance of the target background as viewed by the observer was measured on various occasions with the photomultiplier photometer. For most experiments, the luminance varied between 429 and 495 foot-Lamberts. Inadvertently, the luminance varied to 825 and 845 foot-Lamberts for the experiments involving the 4 minute white and black targets. Visual data previously reported by Blackwell and McCready (Ref.15) reveal that variation in background luminance within these limits will have a negligible effect upon the data. In each case, the luminance of the surround was adjusted to a visual brightness match with the background of the targets.

During each session, 50 presentations were made at each position of the filter wheels. There were blocks of 10 consecutive presentations at each wheel position with the order of the various wheel positions randomized. The raw data are probabilities of correct identification of the temporal interval containing the target, for each of five values of target contrast. The probabilities of correct identification are corrected for chance successes from the relation

$$p' = \frac{p - .25}{1 - .25} \qquad (9)$$

where p' = corrected probability; and
   p = raw probability

As has been shown earlier by Blackwell (Ref.19) probability of detection data obtained as a function of target contrast may be adequately fitted by a normal ogive, at least for targets and backgrounds of uniform luminance. The data obtained in the present experiments were first analyzed in terms of their fit to normal ogives, using visual fits of the data when plotted on the probability grids manufactured by Codex Book Company as paper No. 32.451. The data

for individual observers were analyzed separately. It was found that the experimental probability data for each observer were adequately fitted by normal ogives when values of p' were plotted as a function of a linear scale of contrast, which appear as straight lines on the probability grids. There were differences in the sensitivity of the two observers, resulting in differences in the values of p' at each value of contrast. For convenience in presenting a summary of the data, we have averaged the values of p' for the two observers. As Blackwell (Ref.19) has shown, averaging probability data when there are differences in sensitivity tends to distort the probability curve into the form in which values of p' plotted on a probability scale are a linear function of the logarithm of contrast. For this reason, we have plotted average values of p' as a function of log contrast. Values of contrast (C and C_e) have been plotted in relative units only, since we need attach no significance to the absolute values of these quantities at this point.

2. Results

The probability data for the three target sizes are plotted in Figures 17-19. In each case, the data for dark and bright targets presented against uniform backgrounds are fitted by a solid straight line; the data for bright and dark targets presented against the ball-bearing board are plotted separately, with each set of data fitted by a dashed straight line parallel to the solid line fitted to the data for uniform targets. The adherence of the two individual sets of data to the dashed lines measures the extent to which a value of effective contrast used to describe the detection probability value obtained at one stimulus intensity with the non-uniform background is generalizable to other probability levels. The adherence of the data to the dashed lines is at least as good as the conformity of the data for uniform backgrounds to the solid lines, so that we may conclude that values of effective contrast are generalizable to different levels of detection probability.

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In the earlier analysis of these data (Ref.16), the values for the ballbearing board were presented in terms of C_e, and data for dark and bright targets were presented together. As noted above in connection with the method of adjustment data, later evidence established that the bright and dark target data should not be presented together in terms of values of C_e since the value of $\overline{B}$ corresponding to the average luminance should not be used to compute contrast. Combining the data had the effect of introducing discrepancies between the data obtained with non-uniform backgrounds and the dashed curve used and was misleading.

Also, as we shall see, it is misleading to compute values of β to compare the data obtained with uniform and non-uniform backgrounds as was done in the earlier report. It is worth mentioning here that the values of β presented in the earlier report averaged about .44 for the three target classes being considered here, which was in direct conflict with the value of unity obtained with the same targets in the method of adjustment experiments.

C. Effective Contrast for Various Contrasts, Sizes and Exposure Durations.

The experimental set-up described in the last section was found in general to be unsatisfactory for experimental use. The few data presented required months of concentrated experimental effort, due principally to the almost impossible task of eliminating spurious cues upon which the observers could base correct identifications of the target interval without detecting the target. After some further months spent in attempting to improve the set-up, it was reluctantly abandoned for the set-up based for the experiments to be reported in this section. The new equipment eliminated the use of photographic transparencies and substituted for them a real ball-bearing board viewed directly as in the original method of adjustment experiments. The target was superimposed in front of the ball-bearing board during one presentation interval of four and was absent

during the other three intervals. In this set-up, spurious cues could not be introduced inadvertently since the background was indeed the same during each of the four intervals. The one possible difference among the four intervals was the presence of the target during one interval.

1. Apparatus and Procedures.

The revised apparatus had many similarities to the apparatus described in the last section and shown schematically in Figure 16. In effect, the apparatus was cut away to the right of lens L3 in Figure 16, and a large real-life target was substituted for the optical beams containing the photographic transparencies.

The revised room is shown schematically in Figure 20. The original room measured 12 ft. wide, 12 ft. long, and 8 ft. high. An 8 by 20 ft. extension was built to the right of the original room as shown in Figure 20. The revised optical equipment used to reduce the contrast of the target-background complexes is shown in Figure 21. A cutaway drawing of the target presentation device is shown in Figure 22.

As before the observer sat on one side of a wall. Through an aperture in the wall he was able to see a white uniform surround measuring 11 by 14 inches and located 14.75 inches from his eye. In this case, the surround subtended about 36° in the vertical direction and 43° in the horizontal direction. The surround was illuminated by four lights on the side of the wall opposite from the observer's station, located at a radial distance of 6 inches from the center of the wall. The luminance of the surround was about 360 foot-Lamberts. In the center of this surround there was a 1.5 inch diameter round hole covered from behind by a shutter of the same white material as the surround. Opening this this shutter exposed a real image of the stimulus complex, located in the same plane as the surround. The image of the stimulus complex subtended 5 degrees and 49 minutes. These conditions of observation obviously differed in but minor

details from those involved in the experimental set-up described in the last section.

The target presentation device consisted in part of the ball-bearing board mounted upright at a distance of 19 ft. 4-3/4 inches from lens L3. At this distance, the image of each ball of the non-uniform background subtended 8 minutes of arc. The background was illuminated by a 4 ft. square, 30 inch deep box containing twenty 100 watt light bulbs and painted white inside. The background was mounted close to a 2 ft. circular opening in the back of this box (see Fig. 22) and was illuminated by the light in the box. The observer viewed the background through an opening in the front of the box which was just large enough (19-3/4 inches) to allow him to see a 2 ft. circle of background exposed through the opening in the back of the box.

The target was placed in front of the light box so that it could be illuminated by separate sources of light which would not fall directly on the background. This was done so that the target would not cast a shadow on the background. Experimentation with the target placed as close as possible to the background revealed that under some conditions, the shadow created by the target provided a false cue of greater magnitude than the target itself.

The target was illuminated by two 500-watt projectors mounted between the observer and the front of the target presentation apparatus shown in Figure 20, but concealed from the observer's direct view by baffles. Each projector was aimed at the target from an angle of 45 degrees from the plane of the target. Each projector was on a ramp, one above the target and the other below. The ramps were designed so that the projectors could be moved along the ramps, changing the intensity of illumination on the target. The 45 degree angle was sufficient to prevent direct illumination of the background.

It was found that the wax originally used to hold the ball-bearings in place could not withstand continuous use of the board in an upright position.

Reinforced polyester resin was substituted for the original wax and the surface treatment used in the original case was duplicated.

The target was suspended on two thin wires, each .004 inch in diameter. Each wire passed over pulleys and formed a loop encircling the light box and background. Behind the background there was a lever arm activated by a pneumatic cylinder. This lever arm attached to the two wires could quickly move the wires back and forth along the track of the pulley. Thereby, the target which was attached to these wires, could be quickly placed in or removed from the observer's view. The device was very accurate in positioning the target. Consecutive presentation of the small targets varied considerably less than 1/32 inch.

Lens L3 formed an image of the target-background complex in the plane of the surround which was located 14.75 inches from the observer's eye. The plane of the surround was conjugate with the observer's retina so that he obtained an in-focus view of the target-background complex.

Reduction in contrast was accomplished by adding veiling light and reducing the light from the stimulus complex so that the combined light intensity from the two remained constant. There were two separate systems for reducing stimulus intensity and adding veiling light, the wheel filters and the fixed filters, as shown in Figure 21.

A. The Wheel Filters

The stimulus intensity was reduced by filter wheel 1. The wheel contains five separate filters, any one of which could be placed in the light path by manipulation of a control switch which rotated the wheel into the desired position. The relative transmittances of the filters were as follows: position 1 - 100%; 2 - 75%; 3 - 60%; 4 - 47%; and 5 - 17%. Veiling light was added from lamp La 1 at the top of Figure 21. The beam labeled SV travelled through filter wheel 2 and filter holder F4. Filter wheels 1 and 2 were mechanically linked so that a position of one always implied a given position of the other. These two

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filter wheels were so balanced that the resultant total light intensity remained approximately constant, e.g. position 1 allowed the maximum light through from the stimulus material and a minimum of veiling light, while position 5 allowed the minimum light from the stimulus material and a maximum veiling light.

B. The Fixed Filters

The other source of veiling light (labeled V in Fig. 21) came through filter holder F3 and was added to the main beam by beam-splitter BS1. The contrast of the stimulus material was reduced by adding filters to holder F1 while the same time removing filters from F3 such that the total light intensity remained constant. This was the method used to adjust the contrast to the threshold range of each observer for each target-background complex, and these filters were not changed until the observer had completed all the sessions on a given target. The contrast was varied within the threshold range by means of the previously mentioned wheel filters.

The filter holders F2 and F4 were used to balance the light intensities from the various beams and were frequently readjusted. Filters were put in holder F4 to seuate the intensity of veiling beam SV with the intensity of the beam containing the stimulus material. For this balance, the filter wheels were put in the position of maximum transmittance. Filters were used in holder F2 to equate the intensity of veiling beam V with the total of the SV beam and the beam containing the stimulus complex. For this balance, it was necessary to use a neutral density .3 filter in F3. This degree of density could later be removed in steps as filters were added to F1, and the total luminance maintained approximately constant.

Initially three student observers were used. However, one observer was forced to discontinue his observing because of academic difficulties. The results shown in this study are for the remaining two observers: RL, a 22 year old white male, and AL, a 21 year old white male.

Both observers were uncorrected and had normal vision as tested with the Titmus Optical Co. Vision Tester. Neither observer used any optical aids during his observing. The motivation of the observers seemed to be adequate throughout the entire series of tests.

All measurements of target contrast were made from the observer's position with the photomultiplier photometer. This was done so that the final contrast values would reflect any contrast losses that might occur in the optical system. The surround lights and lamp La 1, whose presence made a contribution to the reduction of contrast, were turned off during this measurement. A separate correction was made for stray light introduced from this source.

A .1 degree aperture was used in the photometer to measure the target luminance. Even this opening was too large for the 4 minute target and it was necessary to place a larger piece of target material in the target position for this measurement.

The .1 degree aperture was too small to integrate a representative portion of the non-uniform background. Therefore, the 1 degree photometer aperture was used to measure the average luminance of the background. When measuring contrast, we therefore temporarily inserted a large uniform surface and first compared its luminance with the luminance of the background using the larger photometer aperture and then compared its llumunance with that of the target using the smaller photometer aperture. Using a modification of equation (1), the contrast becomes:

$$C = \left(\frac{B_t}{B_c} \times \frac{B_c}{B} \right) -1 \qquad (10)$$

0.1 degree   1 degree
aperture   aperture

where B_t = luminance of the target;
B_c = luminance of the large uniform surface; and
B = luminance of the background

In order to insure uniformity of the measurement procedure, this same method was used with the uniform backgrounds.

The basic method of determining the contrast rendition of the optical system shown in Figure 21 was the same as described in the last section. The contrast rendition values for the wheel filters were modified to the following values:

Wheel Position	Contrast Rendition
1	.814
2	.606
3	.478
4	.398
5	.149

The contrast rendition of the filters in holders F1 and F3 may be determined exactly as before.

The luminance of the target background as viewed by the observer was measured with the photoelectric photometer each time the target, background or a projector bulb was changed.

During each session 50 presentations were made at each position of the filter wheels. There were blocks of 10 consecutive presentations at each wheel position with the order of the various wheel positions randomized.

The raw data consisted of the target contrast as modified by the contrast rendition of the apparatus for each of the 5 wheel positions, and the number of correct responses at each position. These data were analyzed by a probit analysis performed on the IBM 704 and 7090 computers and are plotted in the accompanying graphs as the threshold contrast corresponding to $p' = .50$. This probit method follows in general the method of Kincaid and Blackwell (Ref. 20).

As in earlier experiments, the uniform and ball-bearing board backgrounds were used. Targets were the 4, 8, and 24 minute circles studied previously and each target was centered about the center of one of the elements in

the background. The target positions are shown schematically in Figure 23. The open circles are intended to represent the visible tops of the individual ball-bearing elements in the non-uniform background. The principal exposure duration was 1.9 seconds, but a few experiments were conducted with a 0.1 second exposure produced by a rapid-action flag shutter.

The principal new condition of these experiments involved use of a number of values of initial target luminance, so that the values of C and C_e were an experimental variable among sessions. This variation in the target-background complexes was a simple matter to arrange, since the target was illuminated separately from its background. It should be apparent that this is in contradistinction in the earlier studies in which the illumination of the target and background were equal so that target contrast depended solely upon target reflectance with respect to background reflectance and could not be readily varied.

The principal idea behind this experimental variation was to test the generalizability of a method for specifying effective contrast to different values of this quantity. That is, a satisfactory method of specifying effective contrast would lead to a scale of this quantity with the same numerical significance as a scale of physical contrast. This aspect of effective contrast generality was to be tested by examining the extent to which values of $\overline{C}_e$ were equal when different values of C_e were used. To test the absence of experimental errors, the same analysis was to be performed on data obtained with uniform backgrounds, by comparing values of $\overline{C}$ obtained with different values of initial target C. (Any departure of $\overline{C}$ from constancy would have to be indicative of experimental error, since the stimulus situation at threshold should be precisely the same for different values of C).

2. Results.

Data for a 4 minute circle presented on uniform background are

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presented in Table I and Figure 24. Each data point represents the average threshold for 2 observers and involves 500 target presentations. The open circles in the figure correspond to targets brighter than their background; the filled circles represent targets darker then their background. In the tables, the parenthesis represents that the target was darker than its background. As noted above, the value of log $\overline{C}$ should be independent of the initial value of target contrast, so that a horizontal line should describe the data. Such a line is fitted to the data and the grand mean value, M, is shown. The data should be more precise the larger the original value of C, since small values of C present difficult photometric problems. Thus, data scatter would be expected to become progressively worse toward the left of the graph. The precision of the data is no better than $\pm$ .1 log unit which is very poor for this type experimentation. However, it must be realized that the determination of C depends in these experiments upon separate measurements of B_t and B. In all other detection experiments with which we have been concerned, it has been possible to measure the quantity $(B_t - B)$ independentaly of B, which greatly increases the precision with which values of C can be determined.

The data for a 4 minute circle presented against the ball-bearing board background are presented in the first three columns in Table II and in Figure 25. For generality, the coordinates are labeled $\overline{C}$ and C, even though in this case the ordinate is actually computed from values of C_e and hence should be labeled $\overline{C}_e$, and the abscissa should be labeled C_e. The horizontal line corresponds to the average value of $\overline{C}$ obtained with the 4 minute circle presented on the uniform backgrounds. It is obvious that the values of $\overline{C}$ for bright targets depend systematically upon C, although the one point for a dark target falls near the line. The value of $\overline{C}$ increases markedly as C is decreased.

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Data for an 8 minute circle presented on uniform background are presented in Table III and in Figure 26. The horizontal line presents the grand mean value as before.

Data for an 8 minute circle presented on the ball-bearing board background are presented in the first three columns of Table IV and in Figure 27. Here the data agree quite well with the line which represents the mean value for the 8 minute target presented on the uniform background.

Data for a 24 minute circle presented on the uniform background are presented in Table V and in Figure 28. The horizontal line represents the grand mean of the data obtained with the uniform background as before.

Corresponding data for the 24 minute target on the ball-bearing board background are presented in Table VI and in Figure 29. Here, the value of $\overline{C}$ depends upon C as it did with 4 minute circle, but the effect operates in the opposite direction, values of $\overline{C}$ decreasing with the value of C.

These results reveal clearly that $\overline{C}$ is not constant for different values of C but depends upon C to a highly significant extent, in a way which is different for different target sizes. Before considering the significance of this apparently puzzling result, let us consider the few data collected with the 0.1 second exposure duration to ascertain to what extent effective contrast is generalizable to different exposure durations.

The data for 0.1 second exposure duration are presented in Table VII and in Figures 30 and 31. The one value of $\overline{C}$ obtained for each target with a uniform background was used to construct the solid horizontal line in each figure. The data points for the 4 minute target show $\overline{C}$ higher than the line to an increasing extent for smaller values of C, as was found with the 1.9 second data. The one value of $\overline{C}$ for the 24 minute target shows the value lower than the line, as was found with the 1.9 second data. Comparison of the data for the 4 minute target for the two durations (Figures 25 and 30) and for the 24

minute target (Figures 29 and 31) reveals that the discrepancies between the
data points and the lines agree in magnitude. This signifies that the relations
between effective contrast values for the two target sizes and the two exposure
durations are very similar for the ballbearing board data in comparison with the
data obtained with the uniform backgrounds.

D. General Conclusion

Taken together, the results of this section seem to indicate that
effective contrast is indeed generalizable to different adaptation luminances,
probability levels, and exposure durations but that it is not generalizable to
different contrast values or different target sizes. This means that an effect-
ive contrast value will have to be established for each target-background com-
plex consisting as it does of a given pattern of luminance in the background,
and a target of given size and luminance. However, this value of effective
contract will characterize the complex for different conditions of observation
such as level of adaptation luminance, exposure duration, and general contrast
needed to alter the detection probability. Such generalizability for the
effective contrast concept seems of sufficient value to warrant development of
a practical device to assign values of effective contrast to target-background
complexes.

III. DEVELOPMENT OF AN OPTICAL DEVICE TO ASSIGN VALUES OF EFFECTIVE CONTRAST
     TO TARGET-BACKGROUND COMPLEXES*

Blackwell (Ref.21) has previously described an optical device, known
as the Visual Task Evaluator, which can be used in principle to assign a value
of effective contrast to target-background complexes. The device is analogous
in principle to the systems used throughout the experiments reported in earlier
Sections to reduce the contrast of target-background complexes to the visibil-
ity threshold. It is based upon the reduction of contrast by the simultaneous

reduction in light coming from the target-background complex and addition of
unfocused light from a source of veiling luminance. The device can be used to
assign a value of effective contrast to target-background complexes by the simple
expedient of using it to equate the visibility of a complex to a standard task
of known physical contrast. The equation is performed with greatest precision
when both the target-background complex and the standard task are at the visibil-
ity threshold. In his earlier use of this idea, Blackwell described the effect-
ive contrast of visual tasks in terms of the physical contrast of a standard
circular target of 4 minute diameter, presented on a background of uniform lumin-
ance. In the earlier use of this idea, Blackwell used the index of effective
contrast, designated C, to establish the illumination needed to light various
tasks to a criterion level of suprathreshold visibility. In the present connect-
ion, the use of the principle simply stops at establishment of the value of C.

Except for this change in the philosophy of the device, the develop-
ment of a Visual Task Evaluator (VTE) for the present putpose has consisted
solely in redesigning the device to make it reasonable, compact and simple to
use with target-background complexes.

1. Design and Calibration of the VTE

A schematic optical diagram of the modified instrument is presented in
Figure 32. The operator views the external world through a telescopic system
having two possible values of magnification. The view of the world fills the
inner circular area of a photometric comparator cube and subtends 5 degrees of
true field. An internal lamp is used to supply a veiling luminance. This lamp
also supplies an annulus field which is used in matching the veiling luminance
to the luminance of the task. An annulus wedge modifies the intensity of all
beams coming from the internal lamp, so that the veiling luminance and annulus
beams are modified to the same extent by adjustment of the annulus wedge. There
are two veiling luminance beams V_1 and V_2. Beam V_1 is added to the beam from

the external world by reflection from the variable contrast wedge.* Beam V_2 is added to the external beam by reflection from a partially-silvered removable beam splitter. Since the intensity of the external beam is reduced by the variable contrast wedge, the variable contrast wedge reduces task contrast. Insofar as the sum of reflectance and transmittance in both variable contrast wedge and the removable beam splitter are equal for all settings of the variable contrast wedge, the total luminance of the inner circular field remains constant while the contrast is reduced. Considering the situation formally, we may describe the contrast rendidion of the system involving V_1 alone as

$$CR = \frac{B_p t_w}{B_p t_w + B_{v_1} r_w} \qquad (11)$$

where B_p = luminance of the beam from the practical task in the external world;

B_{v_1} = luminance of beam V_1 when reflected by a perfect reflector;

t_w = transmittance of the variable contrast wedge for a given setting; and

r_w = reflectance of the variable contrast wedge for the same setting.

If $t_w + r_w$ = constant for all settings and $B_{v_1} = B_p$,

$$CR = \frac{B_p t_w}{B_p} \qquad (12)$$

Considering both beams V_1 and V_2, the contrast rendition of the system

$$CR = \frac{B_p t_w t_b}{B_p t_w t_b + B_{v_1} r_w + B_{v_2} r_b t_w} \qquad (13)$$

where B_{v_2} = luminance of beam V_2 when reflected by a perfect reflector;

t_b = transmittance of the removable beam splitter; and

r_b = reflectance of the removable beam splitter.

If $t_w + r_w$ = constant for all settings

and if $t_b + r_b$ = constant for various partially-silvered beam splitters,

and if $B_{v_2} = B_{v_1} = B_p$,

$$CR = \frac{B_p t_w t_b}{B_p} \qquad (14)$$

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*Furnished by D.M. Finch of the University of California at Berkeley.

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With this system, variable contrast rendition is introduced with the variable contrast wedge, and fixed steps of contrast rendition are provided by beam splitters with different values of t_b and r_b.

The optical system used in the VTE is shown in detail in Figure 33. The telescopic system used to image the external world consists of two stages. The objective lens with focal length 6.05 inches forms an image of the world just in front of the front surface mirror as shown in the figure. This image is reimaged in the inner circular area of the photometric cube by a lens consisting of two 4.57 inch focal length components. This lens has two positions in order to give two values of magnification of an in-focus image of the external world. Two values of magnification are obtained by locating the erector unit in a terrestrial telescope such as this at an asymmetrical location between the secondary focal plane of the objective and the primary focal plane of the ocular. The second level of magnification is achieved by reversing the asymmetry. The magnification is ten times as great when the lens is in position 2 as when it is in position 1. The operator views the external world as it is presented in focus in the plane of the photometric cube with the aid of an eyepiece with a 2 inch focal length.

The internal lamp illuminates a plate of opal glass, a portion of which is viewed directly by the operator in the form of the annulus field in the photometric cube. A slightly different portion of the opal glass serves as the veiling luminance of beam V_1 by direct view. A larger area of the opal glass serves as the veiling luminance of beam V_2. This area is imaged by the condensor lens at a point the same distance from the variable magnification lens as the image of the external world formed by the objective lens. Thus, the area of the opal glass serving as beam V_2 is focused in the inner field of the photometric cube just as is the image of the external world.

The appearance of the Portable VTE is indicated by the photograph in Figure 34. The device fits in a plastic case, the outside dimensions of which are approximately 12 by 18 inches, by 9 inches high.

In the initial set-up of the device, considerable care must be exercised in the balancing of the various light beams. The procedure is as follows. First, set the variable contrast wedge at maximum reflectance and block the beams from the external world and beam V_2. Then adjust the luminance of beam V_1 by using Wratten neutral gelatine filters until $B_{v1} = B_A$, where B_A is the luminance of the annulus. Then block beam V_1, leave the external beam blocked, and set the variable contrast wedge to minimum reflectance. Place a full-silvered beam-splitter in the location of the removable beam-splitter. Adjust beam V_2 with Wratten neutral gelatine filters until $B_{v2} = B_A$. Next, remove the full-silvered beam-splitter and leave the location of the removable beam-splitter vacant. Leave the variable contrast wedge set for minimum reflectance. Adjust the luminance of' a uniform surface in the external world until it matches B_A. Now insert a sample partially silvered beam-splitter into the location of the removable beam-splitter. If $t_b + r_b = r_b$ fpr the full-silvered beam-splitter, the condition should exist that $B_p = B_{v2}$. If so, the sum $B_p t_b + B_{v2} r_b = B_p = B_{v1} = B_A$. Under these conditions, the photometric comparator field should remain matched for all settings of the variable contrast wedge provided $t_w + r_w =$ constant for all settings. Furthermore, the photometric equivalence should be maintained for all partially-silvered beam-splitter in which $t_b + r_b = r_b$ for the full-silvered beam-splitter. When the partially-silvered beam-splitters were manufactured with chrome, the condition $t_b + r_b = r_b$ for the full-silvered beam-splitter seems to apply well to different partially-silvered beam-splitters, and the expected equivalence of the various photometric quantities is reasonably well realized. The failure in perfect equivalence apparently is due to failure of the variable contrast wedges we have had to satisfy completely the condition $t_w + r_w =$ constant

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for all settings. Small departures of the sum of $t_w + r_w$ from constancy are not at all important, since we measure the values of CR photometrically, and hence will only be troubled by changes in visual adapatation produced by a lack of constancy of the sum, $t_w + r_w$.

Actual values of CR may be measured directly, by measuring the quantities in equation (13). We have made such measurements for each of three partially silvered beam-splitters, utilizing the photoelectric photometer. The results are shown in Figure 35. Each of the three lower curves represents values of CR as a function of the setting of the variable contrast wedge for one or another partially-silvered beam-splitter. The top curve represents the result with no beam-splitter, which makes it analogous to the condition described by equation (11). We note that with the four conditions implied by the three partially-silvered beam-splitters, we are able to cover a total range of contrast rendition of 1,000 to 1 and yet the change in contrast will be reasonably small for small changes in the setting of the variable contrast wedge. The curves in Figure 35 are relatively parallel with respect to the logarithmic scale of CR. They would be perfectly parallel if the conditions of equations (12) and (14) were fulfilled. The slight departures from parallelism are apparently due to the failure of the sum of $t_w + r_w$ to equal a constant, but the departure obviously has only a small effect on the parallelism of these curves.

We require a photometric calibration of the transmittance of the annulus wedge. The curve obtained with the photoelectric photometer is presented in Figure 36. (The rather gradual drop in transmittance for small settings of the annulus wedge is due to the fact that the field of view is cut by an in-focus image of the high density cut-off point in the wedge. The photometer averages this non-uniform luminance to give the rather gradual cut-off which appears in the figure. In practice, we do not use this portion of the wedge due to the non-uniformity.)

We require a value designated B_O. An external field of variable luminance is viewed with the annulus wedge set for maximum transmittance. It was found that the annulus matched a field with luminance equal to 83.5 foot-Lamberts and B_O is given this value. (This value depends upon the output of the l lamp and must be checked periodically.)

We also require a curve expressing the threshold contrast, C_m, for a 4 minute circular test object as a function of the luminance, B, of a uniform background. This was obtained by viewing a test object of variable contrast through a device at various luminous levels. (The variable contrast wedge was set for maximum transmittance, hence the designation C_m). The contrast of the external target was adjusted to threshold at each luminance level, and the value measured with the photoelectric photometer. The results are presented in Figure 37 for VTE operator BSP.

2. Operating Procedure for the VTE

The variable magnification lens is used at the high magnification setting to center the instrument on the target-background complex of interest. Then the device is set for unity magnification for its actual operation. The annulus wedge is adjusted until its brightness matches the average brightness of the target-background complex. The average luminance of the complex is given from the relation

$$\bar{B} = B_O \times T_a \qquad (15)$$

where in our case B_O = 83.5 ft-L; and
T_a is the transmittance read from Figure 36.

A convenient way to handle the calculations from this point on involves defining

$$\beta = \log \bar{B} = \alpha + \beta_O \qquad (16)$$

where α = log T_a and
β_O = log B_O.

In our case, β_O = 1.922. Hence $\beta = \alpha + 1.922$. The ordinate scale in Figure

36 is identified in terms of α for convenience.

A value of C_m is read from Figure 37 at the value of $\overline{B}$. Define $\omega = \log C_m$ and read this quantity at the value of β.

Now, the variable contrast wedge is adjusted to bring the target-background complex to the visibility threshold. The proper partially-silvered beam splitter is selected so that the threshold occurs as near the middle of the range of adjustment of the variable contrast wedge as possible. The value of CR is read from the appropriate curve of Figure 35. The value of effective contrast,

$$\widetilde{C} = \frac{C_m}{CR} \tag{17}$$

This may be computed by reading the value of $= \log CR$ from Figure 35. Then,

$$\gamma = \log \widetilde{C}$$
and
$$\gamma = \omega - \theta$$

the antilog of γ is the value of effective contrast, $\widetilde{C}$.

3. Validation of the VTE

The validity of the Visual Task Evaluator is somewhat difficult to establish, since in a sense if we had some satisfactory way to assign values of effective contrast for a validation measurement, we would not require the device to assign such values. One approach to a study of the validity of the device involves assigning values of $\widetilde{C}$ to various tasks which can be studied physically, and then their effective contrast established by reference to published data relating effective contrast to the physical parameters involved.

We set up a total of 26 circular and rectangular targets against uniform backgrounds. In fact, the 26 targets studied in the method of adjustment experiments were used. The physical contrast of each target was measured with the photoelectric photometer. Then, the equivalent effective contrast of each target was computed by allowing for the difference in contrast required to equate targets of different sizes to a standard 4 minute target. A large target of given contrast was given a larger effective contrast than actual contrast,

because the threshold contrast is less for the large target than for a 4 minute target. Quantitative corrections were drawn from the data of Blackwell and McCready (Ref.15). The computed values of equivalent effective contrast were designated C".

Measurements of $\tilde{C}$ were made at each of five levels of background luminance and the values were averaged. In computing values of C", the correction for target size was made differently for each level of background luminance, in accordance with the threshold data for different target sizes and different background luminances. (The fact that the corrections for target size were made separately for each level of background luminance led to use of the double prime on the value of C). The 26 separate values of C" and $\tilde{C}$ are presented in the first two columns of Table VIII, and as X's in Figure 38.

A similar study was made of the same 26 targets when presented against the ball-bearing board background. The values of physical contrast were based on average luminance as before. The corrections for target size were made in the same way as when the targets were presented on uniform backgrounds. The results are presented in the last two rows in Table VIII and as the triangles in Figure 38.

The VTE could be said to have perfect validity if all the data points fell on the solid line in Figure 38, representing that $\tilde{C} = C"$. If all the data points fell on a straight line parallel to the line of Figure 38, this would signify that $\tilde{C} = k C"$. The data to be given most serious consideration are, of course, the values for the targets presented against the uniform backgrounds. It appears as if $\tilde{C} = k C"$ where k = 1.26. This result could signify that the values of C_m presented in Figure 37 are in error by 0.1 log units. Or, of course, there could be other more complex interpretations of the experimental results. The only justification for preventing the data for non-uniform back-

grounds here is that study of these very targets by the method of adjustment, as reported in an earlier section, showed that $\bar{C}$ = unity. This signified that the values of $\bar{C}_e$ were equal to the values of $\bar{C}$ for the same targets presented against uniform backgrounds. We have seen in the last section that the values of $\bar{C}_e$ do not always agree with the values of $\bar{C}$, but they do agree for the particular target-background complexes studied here. If we include the data obtained with non-uniform backgrounds, we conclude that the values of $\tilde{C}$ agree better than those of C". There is still a suggestion that perhaps $\tilde{C}$ = kC" but the value of k would be no greater than 1.10.

Considering the rather poor precision of the procedures involved, the degree of agreement between the values of $\tilde{C}$ and C" in Figure 38 is not bad. We can perhaps consider that the VTE has validity as a device for assigning values of effective contrast.

IV. ANALYTIC STUDIES OF THE EFFECTS OF BACKGROUND AND TARGET LUMINANCES UPON EFFECTIVE CONTRAST.

The data obtained with the 4, 8, and 24 minute targets presented against the ball-bearing board background for various initial values of C_e were analyzed to determine what rational principles might be in operation to produce the complex results observed. Originally, our attention was directed toward the noise-masking effect we believed the elements of non-uniformity of the background would have upon the targets.

Our procedure involved what seemed to be an artifactual complication from the point of view of an hypothetical noise-masking effect. The initial value of C_e obviously directly affected the contrast rendition, CR, the optical system had to introduce to bring the target-background complex down to threshold visibility. The greater the initial value of C_e, the greater the CR required. The complication was that the degree to which the elements of non-uniform luminance in the background were visible depended upon CR and hence upon the

initial value of C_e. Put another way, when C_e was very large, the target was very visible compared to the ball-bearing elements and hence, at threshold, the elements might well be invisible and hence could not be expected to produce any noise-masking effect.

In order to evaluate the noise-masking effect, we required an estimate of the visibility of the elements of non-uniformity of the ball-bearing board themselves. Our experimental set-up did not permit us to use the non-uniform background in the target position, and determine the visibility of its elements per se in the usual manner. We therefore mounted a large circular target subtending 149 minutes of arc in the target position and used it to simulate the uniform background in the central fixation area. Its luminance was made equal to the average luminance of the non-uniform background against which it was seen in one of the four target presentation intervals. The presence or absence of this target was detected by the observer, by noting the presence or absence of the non-uniformity in the central fixation area. By this means we found the threshold of visibility of the elements of the background to equal 0.00856 on the average for the two observers.

We may relate this value to the CR required to produce it with the values of luminance actually present with the ball-bearing board background. The value of C_e may then be computed for each target which is just at threshold at this value of CR. The obtained values of C_e were as follows: 4 minute target: 1.85; 8 minute target: 1.06; and 24 minute target: .425. In logarithmic units these are .267, .026, and -.372 for the 4, 8, and 24 minute targets.

With these data at hand, we can examine our earlier results. The data for the 4 minute target (Figure 25) reveal that all the data points in which log $\bar{C}$ is above the horizontal line come at values of log C below .267. At all values below .267, the ball-bearing board elements would be visible. They would be increasingly visible for smaller values of log C. The increase in log $\bar{C}$ with

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decrease in log C could then be accounted for by postulating a noise-masking effect of greater magnitude the more visible the ball-bearing elements were at the threshold of the target-background complex. This seemed quite reasonable. The 8 minute target data (Figure 27) all fall at values of log C below .026, so that the ball-bearing elements were visible at the threshold of the target-background complex also. In this case, however, there was no deleterious effect due to the presence of a non-uniform background; that is, $\overline{C}_e$ was not greater on the average than $\overline{C}$, and this in spite of the fact that the elements of the ball-bearing board background were of exactly the proper size to produce maximum noise-masking effect (Ref.3) Finally, the data for the 24 minute target (Figure 29) fall half above and half below the value of log C equal to -.372. Thus, the two data points to the right along the scale of log C actually represented cases in which the ball-bearing elements were not visible at the threshold of the target-background complex. All the data seem to fall on a single curve and the effect is opposite to that to be expected from a noise-masking effect.

This analysis left us quite puzzled as to the significance of our results. Different analytic treatments of the data were investigated. Finally analysis suggested, as described in our second report (Ref.22), that we could understand our data in terms of the contrasts of our targets with respect to the points on the ball-bearing board background immediately adjacent to the border of each target.

Before describing the analysis of our data in these terms, let us read into the record the data we obtained with the 4 minute target positioned direct-ly over the space between the elements of the ball-bearing board. The data are presented in the first three columns of Table IX and in Figure 39. The horizon-tal line is the grand mean of the data obtained with the 4 minute target on uni-form backgrounds. We see that, unlike the results obtained when this target was centered over an element of the background, the data agree quite well with the

line and show no appreciable dependence of the value of log $\bar{C}$ upon the initial value of log C.

Our quantitative analysis of the effects of background and target luminances began with a very careful study of the luminances of points on the ball-bearing board, utilizing the photoelectric photometer fitted with a telescopic objective. The average results of measuring local luminance values in various parts of the board are given in Figure 40. Based upon these data, we can construct luminance cross-sections through various portions of the ball-bearing board, with the results shown in Figures 41-43. The horizontal straight line represents in each case the average luminance of the entire ball-bearing board in the relative units used in the plots of our luminance information. In Figure 41, we see the location of the centered 4, 8 and 24 minute targets with respect to the pattern of luminance of the ball-bearing board behind them, with respect to orthogonal traces through the background. Both the centered 4 minute target and the 8 minute target are symmetrically located with respect to the luminance pattern of the ball-bearing board elements. We may indicate on the figure with suitable arrows the luminance of the ball-bearing board elements at the center (C) and at the border (B) of each of these targets. Thus B4 represents the luminance at the border of the centered 4 minute target, C8 represents the luminance at the center of the 8 minute target, and so on. In the case of the 24 minute target, B24 in Figure 41 represents the luminance of the ball-bearing board at the border of the 24 minute target along orthogonal lines only.

The 4 minute target centered between the elements is represented in Figures 42 and 43, and the luminances of the ball-bearing elements at its center and border are indicated. The value at the center is fixed, but the luminance around the border varies from comparatively high value along the orthogonal trace (Figure 42) to the much lower value along the diagonal trace, where the

border of the target is farther from the center of the elements. The border luminance for the 24 minute target varies from the low value shown in Figure 41 along the orthogonal trace to the value for C24 when the border intercepts the center of one of the ball-bearing elements (see Figure 23).

We have re-analyzed all our data for the 4, 8 and 24 minute circles by considering alternately that the center and the border luminance of the ball-bearing board should be considered the target background in defining the effective contrast. Values of C_e based upon the average luminance may be converted by means of the relation:

$$C_e' = \left[(C_e + 1) \; f \right] \; -1 \qquad (19)$$

where C_e' is the corrected value for a
different assumed background luminance; and

$$f = \frac{\overline{B}}{\hat{B}} \qquad (20)$$

where $\hat{B}$ is the assumed luminance.

The computed values of C_e' and $\overline{C}_e$ are presented in Tables II, IV, .VI and IX for the alternate assumptions that the proper background is the border or the center luminance. (These values are identified in the tables in terms of the generic symbols log C and log $\overline{C}$).

The data are plotted in Figures 44-51. In each case, the horizontal line represents the grand mean value of log $\overline{C}$ for the target in question when presented on the background of uniform luminance. The agreement between the data and the lines is very good indeed for all targets when the border luminance is used to define contrast. It is equally good for the centered 4 minute target when the center luminance is used to define contrast, since the border and center luminances are in this case very similar. Data based upon center luminance disagree grossly with the straight lines for the other three cases. It thus appears clear that it is the border luminance, not the center or average luminance which properly describes the effective contrasts of targets seen against

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the ball-bearing board background of non-uniform luminance.

The situation is somewhat complicated for the 24 minute target and for the 4 minute target centered between the elements of the ball-bearing board background, since the border luminance was not uniform around the perimeter of these targets. The variation in the value of border contrast around the perimeter of the 4 minute target may be judged by reference to Table X. The usual contrast occurred at the points shown in Figure 42. The occasional contrast occurred at the points shown in Figure 43. The plot in Figure 47 is based upon the usual C. Data computed on this basis are shown to agree with the data obtained with a uniform background, which presumably signifies that it is these values of C which are relevant to the visibility of the target. The occasional contrasts are much higher but apparently occur over a sufficiently small portion of the perimeter of the target so as to be unimportant. Data on the usual and occasional contrast values for the 24 minute target are presented in Table XI. Again, the plotted data in Figure 51 have been based upon the usual C. The occasional C is always lower and occupies nearly 40% of the perimeter. The evidence in Figures 51 and 52 suggests that the value of $\overline{C}$ for this target is about 25% too high in comparison with the data for uniform backgrounds and the existence of the portions of the target perimeter with lower contrast may very well provide the explanation for the observed discrepancy.

The data obtained with the ball-bearing board background may be summarized with respect to the relation between target size and $\overline{C}$, as has been done in Figure 52. The data for uniform backgrounds and the data for the non-uniform background agree well when the latter are based upon the luminance of the ball-bearing board at the target border. Furthermore, the relation between size and threshold contrast defined by the smooth curve of Figure 52 can be said to be consistent with the more extensive data of Blackwell and McCready (Ref.15).

The generality of the conclusions reached on the basis of the ball-bearing board background were tested in a second series of experiments involving a checkerboard background. This background had the advantage that there were only two levels of luminance, white and black, and that the two levels could be made much more different than those which could be achieved with the ball-bearing board.

1152 one-inch squares of white paper, and an equal number of black squares were mounted in a checkerboard array in a flat square board, measuring 4 feet on a side. A 2-foot square photographic reproduction was made and this was used as the checkerboard background. Each square measured exactly .5 inch on a side, and the luminance borders were very sharp. Each square subtended 8 minutes on a side at the viewing distance used. The checkerboard background was mounted in the target presentation apparatus and photometered. The luminances were found to be as follows: white squares: 202 foot-Lamberts; black squares: 9.6 foot-Lamberts; average: 96 foot-Lamberts.

Square targets were used which measured 4, 6, and 8 minutes on a side. The method of mounting the targets, and all other details of the experiment were as described above in connection with the experiments involving the ball-bearing board background.

Data for a 4 minute square presented on uniform backgrounds are presented in Table XII and in Figure 53. For some unknown reason, the data scatter is greater than in the earlier experiments. Separate experiments were conducted with a 4 minute square target on a black and on a white square of the background. The data for the target on a black square are presented in Table XIII and in Figures 54 and 55. Data are presented as before in terms of values of $\overline{C}$ and C based upon the average luminance, and based upon the border or center luminance since the two are equivalent. It is clear that the values of $\overline{C}$ vary very grossly with C when average luminance is used as the basis of calculation. The variation

in $\bar{C}$ when the average luminance is used as the basis of calculation is larger than was found in the ball-bearing board experiments. This result is to be expected, due to the larger difference between the "erroneous" average luminance and the "correct" border luminance values. The horizontal line in Figure 55 does not represent the grand mean threshold for the 4 minute square presented on uniform backgrounds. It represents rather the mean of the data obtained with the checkerboard background. The mean threshold with the checkerboard background is considerably higher than that found with uniform backgrounds, in part due no doubt to the lower level of background luminance but due no doubt in greater part to the increase in ocular stray light produced by the bright elements of the background surrounding the dark background area upon which the target appeared.

Data for the 4 minute square presented on a white square of the background are contained in Table XIV and in Figures 56 and 57. As before, the values of $\bar{C}$ vary grossly with C when average luminance is used as the base but do not vary appreciably when border or center luminance is used as the base. The average value of $\bar{C}$ based on border luminance is indicated by the line in Figure 57. In this case, it is somewhat less than the value for the uniform background, in part no doubt due to the higher level of background luminance but due no doubt also to the reduction in ocular stray light produced by the dark elements of the bakcground surrounding the bright background area upon which the target appeared.

Data for the 6 minute square produced on uniform backgrounds are presented in Table XV and in Figure 58. Data for the same target presented on a black square of the background are contained in Table XVI and in Figures 59 and 60. The results are entirely analogous to the results found with the 4 minute square presented on a black square of the checkerboard background.

Data for an 8 minute square on uniform backgrounds are presented in
Table XVII and Figure 61. Data for the same target presented on a black square
of the background are contained in Table XVIII and Figures 62-64. Here, we
have computed values of C and $\bar{C}$ separately for the border and center luminances.
The border luminance is of course provided by a white square and the center
luminance is provided by a black square of the checkerboard background. Examin-
ation of Figures 63 and 64 reveals a clear reversal of the result found with all
other targets, since the value of $\bar{C}$ is invariant with C when center rather than
border luminance is used as the basis for calculations. This result must, we
believe, be attributed to a special feature of our experiment. As noted above,
the observers can use any cue available to them in detecting the interval
occupied by the target. In this case, the "target" precisely covered one black
square. Therefore, the observers could identify the target by noting a lack of
uniformity in the blackness of adjacent black squares. In a sense, they would
be detecting a lack of uniformity in the checkerboard pattern rather than the
presence of a target as such. Such an interpretation places the results obtain-
ed with the 8 minute square in the category of representing a rather elegant
artifact, and we believe this to be the case. This interpretation does under-
score what must be conceded is a danger in the use of forced-choice psycho-
physics, that cues not deliberately provided by the experimenter can be used
to add to the confusion of the experimenter.

Finally, a 4 minute square was studied when it was centered on the
line delineating the border between a black and a white square in the checker-
board. The data are presented in Table XIX and in Figures 65-68. The values
of $\bar{C}$ and C have been computed on the basis of average luminance, white square
luminance, and black square luminance, with the results shown in Figures 65-67.
In each case, the variation in $\bar{C}$ as a function of C is large. Thus, this

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target does not behave as if any one of these luminances is its effective background.

It occurred to us that this target should be understood in terms of whichever of its two values of contrast with the background was the larger. Examination of Table XIX reveals that in all but one case, the contrast of the target is much larger against the black than against the white square. Thus, we might expect values of $\bar{C}$ to be invariant with respect to C when computed on the basis of the luminance of the black square, excepting for the one data point. Examination of Figure 66 reveals that this expectation is not borne out. It occurred to us that, in this case, also, we might have inadvertently become involved with the artifact. Suppose we assume that the observers base their discrimination again upon the existence of a uniform checkerboard pattern. In this case, they would see the non-uniformity as a break or discontinuity in the border between the black and white squares serving as the background for the target. Either "half" of the target could serve to break the border, and which half would be effective would depend upon the target luminance. Such reasoning leads to the prediction that for every value of target luminance, there would be a break in the border and this might always be impossible to hide without reducing the value of CR until the pattern in the checkerboard was itself invisible. In such a case, the value of CR would be constant regardless of the value of the target contrast. The data presented in Figure 68 show that this was indeed the case.

This reasoning led us to conclude that the basic principle that target visibility in target-background complexes can be understood in terms of border luminance is correct, unless the experimental procedure permits operation of an artifact such as is believed to have existed with both the 8 minute square and the 4 minute square centered on the border between a black and a white square. We decided to test the generality of our conclusion with a more complex back-

ground than we had used previously, but one which did not feature the special
regularity which in a sense got us into trouble with the checkerboard background.

We selected an aerial photograph of a terrain site produced by photo-
graphing a scale model simulator in connection with two studies of aerial photo-
interpretation variables (Ref.23, 24). We made a paper print measuring 2 feet
on a side, and mounted the print in the target presentation apparatus as before.
In different experimental sessions a 4 minute square target was superimposed
over one of two different areas of the background, arranged by moving the photo-
graphic background under the target between experimental sessions. The appear-
ance of the target and background may be judged from Figures 69 and 70. Data
were collected on only one of our two observers, AL. They are presented in
Table XXI and in Figures 71 and 72. Although the precision is somewhat less
than in the studies with two observers, it seems clear that the value of $\bar{C}$
is invariant as a function of C when the border luminance is used as a basis
for calculations, but not when the average luminance is used. It should be
noted that the center and border luminances in the aerial photo background were
equivalent as far as we could tell by direct measurement.

V. GENERAL CONCLUSIONS

We conclude that the visibility of targets in target-background com-
plexes of non-uniform luminance can probably be best understood in terms of the
contrast made by the target with respect to its background at the target border.
In many cases, this will be equivalent to the target contrast with respect to
the background at the target center or over the entire area of background
occupied by the target. It appears clear that it is not meaningful to describe
target contrast in terms of the average luminance of the background.

Other factors may become involved under special circumstances in
which the background consists of a regular pattern of luminance differences.

However, these effects will not be expected with "natural" backgrounds involving as they usually do essentially unpatterned luminance differences. Local adaptational and stray light effects must also be considered when the luminance differences within the background are large in magnitude.

The use of an optical device to assign effective contrast values has some promise. However, perhaps physical measurements of border contrast are a preferable method to define effective contrast. Unfortunately, we have no direct evidence on this point.

It is possible to tie together the results of the early experiments with the results of the later experiments in the following ways. First, the fact that values of $\bar{C}$ and $\bar{C}_e$ were approximately equivalent in the method of adjustment experiments when C_e was computed on the basis of the average luminance of the background is seen to be no more than a lucky accident, dependent entirely upon the fact that the initial target contrasts which were used fell in the range from .8 to 4. for targets brighter than the background, and had the value of about -.8 for targets darker than the background. Scrutiny of data graphs for the 4, 8 and 24 minute targets presented on the ball-bearing board background (Figures 25, 27, 29) reveals that in this range of values of C_e, the values of $\bar{C}$ and $\bar{C}_e$ are about equal. The fact that values of $\bar{C}$ and $\bar{C}_e$ were not equal in the method of constant stimulus experiments involving the photographic transparencies cannot be reconciled with the other data at all. It will be recalled that the value of $\bar{C}_e$ was about twice as large as the value of $\bar{C}$ for each target size. The values of target contrast during these experiments were very similar to those employed in the method of adjustment experiments, and we would expect on the basis of the results of the later more complete experiments that the values of $\bar{C}_e$ should have equalled the values of $\bar{C}$. There must have been some source of constant experimental error in the experiments involving the photographic transparencies. For example, it can be shown that the results obtained

with the 24 minute target were at so low an initial contrast that the ball-bearing elements of the background would not even have been visible at the threshold value of CR. It is difficult to see how invisible elements of non-uniformity of the background could raise the threshold contrast of a target by a factor of 2. Considering the great complexity of the experimental procedures involved with the use of the photographic transparencies, the existence of a constant error of this magnitude is perhaps not surprising.

The only information actually derived from the method of adjustment studies utilizing the photographic transparencies concerned the generalizability of a value of effective contrast to different probability levels. We can obtain much more accurate evidence on this point by evaluating the results of probit analysis carried out on the data collected by the method of constant stimulus with the backgrounds viewed directly. Each probit analysis yields a value of the quantity σ/M, which measures the steepness of the probability ogive relative to the threshold. The results of analysis of a total of 59,000 data are presented in Figure 73, as average values of σ/M for targets presented against uniform and non-uniform backgrounds. The average values are .414 for uniform and .472 for non-uniform backgrounds. The degree of difference between these two values may be evaluated by the degree of similarity of the two straight lines of Figure 73, which represent normal ogives with these values of σ/M when plotted on probability grids. These data support well our contention that a value of effective contrast can be generalized from one probability value to another. Thus, we can completely ignore the data obtained in our study using the method of constant stimulus with the photographic transparencies without any fundamental loss in the information produced by our entire research program.

VI. RECOMMENDATIONS

It is recommended that further studies be conducted to evaluate the generality of our conclusion that the effective contrast of a target in a target-background complex of non-uniform luminance may be expressed in terms of the contrast the target makes with the background at its border. This conclusion should be investigated in particular with realistic backgrounds such as are represented by an aerial terrain photograph.

It is further recommended that the usefulness of using the Visual Task Evaluator to specify effective contrast be evaluated relative to the usefulness of specifying effective contrast on the basis of physical measurements of the contrast the targets make with the luminance of the background at the target border.

It is recommended also that study be made of the effective contrast of targets in target-background complexes under conditions in which the observer must search for the target, since our experiments have been limited entirely to cases in which the observers knew precisely where the target would appear.

BIBLIOGRAPHY

1. Blackwell, H.R. Contrast Thresholds of the Human Eye. J. Opt. Soc. Amer. 36, 624-643 (1946)

2. Blackwell, H.R. Visibility of Targets: Record of Research. L. C. Tiffany Foundation, Oyster Bay, N.Y. pp. 2746 (1945)

3. Gordon, D.A. and Lee, G.B. Model Simulator Studies of the Night Visibility of Military Targets as Related to Position of Artificial Illuminants. University of Michigan Research Institute, Project MICHIGAN Report 2144-341-T (1958)

4. Hamilton, C.E. Model Simulator Studies of the Visibility of Military Targets at Night. University of Michigan Research Institute Report 2699-1-F (1958)

5. Harcum, E.R. Visual Detection and Recognition of Non-uniform Targets Against Uniform Backgrounds. University of Michigan Research Institute Report 2643-2-F (1958)

6. Blackwell, H.R. Neural Theories of Simple Visual Discriminations. J. Opt. Soc. Amer., 53, 129-160, (1963)

7. Kincaid, W.M., Blackwell, H.R., and Kristofferson, A.B. Neural Formulation of the Effects of Target Size and Shape upon Visual Detection. J. Opt. Soc. Amer., 50, 143-148 (1960)

8. Graham, C.H., Brown, R.H., and Mote, F.A. Jr. The Relation of Size of Stimulus and Intensity in the Human Eye: I. Intensity Thresholds for White Light. J. Exp. Psychol. 24, 555-573 (1939)

9. Kristofferson, A.B. and Blackwell, H.R. The Effects of Target Size and Shape on Visual Detection: I. Continuous Foveal Targets at Moderate Background Luminance. University of Michigan Research Institute, Project MICHIGAN Report 2144-279-T (1958)

10. Blackwell, H.R. and Smith, S.W. The Effects of Target Size and Shape on Visual Detection: II. Continuous Foveal Targets at Zero Background Luminance. University of Michigan Research Institute, Project MICHIGAN Report 2144-334-T (1958)

11. Smith, S.W., Blackwell, H.R., and Cutchshaw, C.M. The Effects of Target Size and Shape on Visual Detection: III. Effects of Background Luminance, Duration Wavelength, and Retinal Location. University of Michigan Research Institute, Project MICHIGAN Report 2144-298-T (1958)

12. Kristofferson, A.B. and Dember, W.N. The Detectability of Targets Consisting of Multiple Small Points of Light. University of Michigan Research Institute, Project MICHIGAN Report 2144-298-T (1958)

13. Kristofferson, A.B. and O'Connell, R.H. The Detectability of Targets Containing Internal Luminance Gradients. University of Michigan Research Institute, Project MICHIGAN Report 2144-297-T (1958)

14. Blackwell, H.R. and Clark, W.C. Relations between Visibility Thresholds for Single and Double Pulses. University of Michigan Research Institute, Project MICHIGAN Report 2144-343-T (1959)

15. Blackwell, H.R. and McCready, D.W. Jr. Foveal Contrast Thresholds for Various Durations of Single Pulses. University of Michigan Research Institute Report 2455-13-F (1958)

16. Blackwell, H.R. and Bixel, G.A. The Visibility of Non-Uniform Target Background Complexes: I Preliminary Experiments. Ohio State University, Institute for Research in Vision and Research Foundation, RADC-TR-60-99 (1960)

17. Blackwell, H.R. Studies of Psychophysical Methods for Measuring Visual Thresholds. J. Opt. Soc. Amer. 42, 606-616 (1952)

18. Blackwell, H.R. Psychophysical Thresholds: Experimental Studies of Methods of Measurement. University of Michigan, Engineering Research Bulletin No. 36, 227 P. (1953)

19. Blackwell, H.R. Studies of the Form of Visual Threshold Data. J. Opt. Soc. Amer., 43, 456-463 (1953)

20. Kincaid, W.M. and Blackwell, H.R. Application of Probit Analysis to Psychophysical Data: I Techniques for Desk Computation. University of Michigan Research Institute, Project MICHIGAN Report 2144-283-T (1958)

21. Blackwell, H.R. Development and Use of a Quantitative Method for Specification of Interior Illumination Levels on the Basis of Performance Data. Illum. Engng. N.Y., 54, 317-353 (1959)

22. Bixel, G.A. and Blackwell, H.R. The Visibility of Non-Uniform Target Background Complexes: II Further Experiments. Ohio State University, Institute for Research in Vision and Research Foundation. RADC-TDR-63-60 (1961)

23. Blackwell, H.R., Ohmart, J.G. and Brainard, R.W. Some Psychophysical Factors in Aerial Photo Interpretation. Ohio State University, Institute for Research in Vision and Research Foundation. Technical Report RADC-TR-61-86 (1961)

24. Blackwell, H.R., Ohmart, J.G., and Brainard, R.W. Experimental Evaluation of Optical Enhancement of Literal Visual Displays. Ohio State University, Institute for Research in Vision and Research Foundation. ASD Technical Report 61-568 (1961)

TABLE I: 4 minute Circles on Uniform Backgrounds

N = 8,500

Date	Log C	Log $\bar{C}$
4-20-61	.018	-1.552
4-21-61	.577	-1.710
4-28-61	-.436	-1.924
5-4-61	-.043	-1.702
5-11-61	-.418	-1.698
5-12-61	.604	-1.772
8-17-61	-.480	-1.622
8-18-61	-.336	-1.532
8-23-61	-.148	-1.743
8-28-61	.082	-1.736
8-31-61	-.678	-1.561
9-5-61	-.404	-1.686
9-11-61	-.433	-1.515
9-12-61	-.500	-1.552
9-14-61	-.138	-1.542
9-18-61	.176	-1.578
9-21-61	(-.574)	-1.630

TABLE II: 4 minute Circles Centered on Elements of Ballbearing Board Backgrounds

N = 4,000

Date	Average Luminance		Border Luminance f = .782		Center Luminance f = .750	
	log C	log $\bar{C}$	log C	log $\bar{C}$	log C	log $\bar{C}$
4-24-61	.528	-1.652	.384	-1.796	.360	-1.822
4-25-61	-.162	-1.433	-.495	-1.766	-.574	-1.844
5-5-61	-.074	-1.630	-.356	-1.914	-.418	-1.974
5-8-61	-.474	-.852	-1.367	-1.746	-2.698	-3.078
5-15-61	-.369	-1.062	-.936	-1.629	-1.149	-1.842
5-23-61	-.257	-1.158	-.672	-1.574	-.780	-1.682
8-15-61	-.426	-.799	-1.130	-1.504	-1.508	-1.881
9-21-61	(-.578)	-1.675	(-.372)	-1.467	(-.349)	-1.445

TABLE III: 8 minute Circles on Uniform Backgrounds

N = 1,500

Date	log C	log $\overline{C}$
4-11-61	-.645	-1.858
4-14-61	-.330	-1.955
4-17-61	.022	-1.832

TABLE IV: 8 minute Circles Centered on Elements of Ballbearing Board Backgrounds

N = 1,500

Date	Average Luminance		Border Luminance f = .987		Center Luminance f = .750	
	log C	log $\overline{C}$	log C	log $\overline{C}$	log C	log $\overline{C}$
4-12-61	-.752	-1.890	-.795	-1.934	-.932	-2.070
4-13-61	-.415	-1.758	-.438	-1.780	-1.420	-2.762
4-18-61	-.052	-1.915	-.064	-1.927	-.381	-2.244

TABLE V: 24 minute Circles on Uniform Backgrounds

N = 4,000

Date	log C	log $\bar{C}$
3-21-61	-.674	-2.034
3-24-61	-.168	-1.920
3-28-61	-.375	-2.198
4-3-61	-.522	-2.125
4-4-61	-.056	-2.152
4-5-61	-1.003	-2.229
4-7-61	-.513	-2.170
4-10-61	-.576	-1.984

TABLE VI: 24 minute Circles Centered on Elements of Ballbearing Board Backgrounds

N = 2,500

Date	Average Luminance		Border Luminance f = 1.50		Center Luminance f = .750	
	log C	log $\bar{C}$	log C	log $\bar{C}$	log C	log $\bar{C}$
3-17-61	.229	-2.220	.484	-1.964	.011	-2.438
3-20-61	-.630	-2.585	-.070	-2.026	(-1.131)	-3.088
3-22-61	-.714	-2.712	-.102	-2.099	(-.979)	-2.977
3-23-61	-.198	-2.278	.161	-1.917	-.647	-2.726
3-29-61	-.479	-2.506	-.001	-2.029	(-3.000)	-5.026

TABLE VII: Circular Targets Presented for 0.1 second Duration - Average Luminance Basis

N = 2,500

Date	Diameter (minutes)	Background	log C	log $\bar{C}$
5-24-61	4	Ballbearing Board	-.130	-1.136
5-29-61	24	Uniform	-.568	-1.688
5-31-61	24	Ballbearing Board	-.532	-2.000
6-9-61	4	Uniform	-.336	-1.316
6-18-61	4	Ballbearing Board	-.324	-1.012

TABLE VIII: Validation of the Visual Task Evaluator with Targets presented on Uniform and Ballbearing Board Backgrounds

Target Characteristics	Uniform Background		Non-uniform Background	
	log C''	log $\widetilde{C}$	log C''	log $\widetilde{C}$

A. Ballbearing Board Elements of 3.08 minute diameter

Target Characteristics	log C''	log $\widetilde{C}$	log C''	log $\widetilde{C}$
1.54 minute circle-dark	-.838	-.573	-.910	-.686
3.08	-.272	-.265	-.347	-.129
9.23	.220	.494	.149	.327
36.9	.455	.716	.391	.726
73.8	.522	.701	.428	.660
1.54 minute circle-bright	-.569	-.374	-.209	-.235
3.08	.033	.179	.401	.299
9.23	.556	.763	.920	.954
36.9	.794	1.072	1.156	1.164
73.8	.877	1.069	1.252	1.279

B. Ballbearing Board Elements of 8.00 minute diameter

Target Characteristics	log C''	log $\widetilde{C}$	log C''	log $\widetilde{C}$
4 minute circle-dark	-.062	-.100	-.085	-.178
8	.164	.336	.131	.326
24	.360	.681	.308	.642
4 minute circle-bright	.248	.201	.436	.448
8	.543	.724	.739	.954
24	.760	.982	.954	1.202
4 x 80 minute rectangle-dark	.522	.632	.428	.480
8 x 80	.532	.706	.440	.719
16 x 80	.538	.824	.444	.712
48 x 80	.540	.795	.446	.616
80 x 80	.540	.743	.446	.734
4 x 80 minute rectangle-bright	.872	.904	1.251	.975
8 x 80	.888	.996	1.262	1.168
16 x 80	.894	1.037	1.265	1.091
48 x 80	.895	1.006	1.268	1.128
80 x 80	.895	1.034	1.268	1.105

TABLE IX: 4 minute Circles Centered between Elements of Ballbearing Board Backgrounds.

N = 5,000

| | Average Luminance | | Border Luminance F = 1.073 | | Center Luminance f = 2.025 | |
Date	log C	log $\overline{C}$	log C	log $\overline{C}$	log C	log $\overline{C}$
8-16-61	-.461	-1.842	-.354	-1.733	.236	-1.144
8-21-61	-.296	-1.747	-.211	-1.662	.312	-1.139
8-24-61	-.202	-1.820	-.126	-1.744	.362	-1.256
8-25-61	.068	-1.706	.124	-1.652	.532	-1.244
9-1-61	-.588	-1.789	-.456	-1.656	.188	-1.014
9-6-61	-.413	-1.673	-.313	-1.574	.256	-1.006
9-8-61	-.386	-1.702	-.289	-1.605	.274	-1.042
9-12-61	-.485	-1.641	-.372	-1.528	.226	-.930
9-14-61	-.142	-1.546	-.074	-1.480	.394	-1.011
9-18-61	.180	-1.557	.228	-1.509	.611	-1.126

TABLE X: 4 minute Circles Centered between Elements of Ballbearing Board Backgrounds.

| | Border Luminance | |
Date	Usual C f = 1.073	Occasional C f = 1.765
8-16-61	.443	1.37
8-21-61	.615	1.66
8-24-61	.747	1.87
8-25-61	1.33	2.83
9-1-61	.350	1.22
9-6-61	.486	1.44
9-8-61	.514	1.49
9-12-61	.424	1.34
9-14-61	.843	2.03
9-18-61	1.69	3.42

TABLE XI: 24 minute Circles Centered on Elements of Ballbearing Board
Backgrounds.

Date	Border Luminance	
	Usual C f = 1.50	Occasional C f = .750
3-17-61	3.05	1.02
3-20-61	.851	.074
3-22-61	.790	.105
3-23-61	1.45	.225
3-29-61	.998	.001

TABLE XII: 4 minute Squares on Uniform Backgrounds

N = 7,000

Date	log C	log $\bar{C}$
1-19-62	-.118	-1.677
1-26-62	-.270	-1.742
2-2-62	-.651	-1.890
2-9-62	-1.285	-1.814
2-19-62	(-.529)	-1.532
2-23-62	(-.268)	-1.504
3-6-62	(-.148)	-1.500
3-19-62	(-.084)	-1.677
3-22-62	(-.204)	-1.806
5-4-62	-.534	-1.684
5-8-62	-.548	-1.731
5-10-62	-.534	-1.594
5-14-62	-.532	-1.723
5-16-62	-.136	-1.463

TABLE XIII: 4 minute Squares on Black Squares of Checkerboard Backgrounds

N = 4,000

Date	Average Luminance		Border or Center Luminance f = 10.	
	log C	log $\bar{C}$	log C	log $\bar{C}$
1-19-62	-.118	-1.990	1.221	-.652
1-26-62	-.270	-2.144	1.158	-.715
2-2-62	-.651	-2.363	1.050	-.662
2-9-62	-1.285	-2.921	.979	-.658
2-19-62	(-.529)	-2.100	.781	-.791
2-23-62	(-.268)	-1.720	.556	-.896
3-6-62	(-.148)	-1.115	.279	-.688
3-19-62	(-.084)	-.616	-.124	-.656

TABLE XIV: 4 minute Squares on White Squares of Checkerboard Backgrounds

N = 4,000

Date	Average Luminance		Border or Center Luminance	
	log C	log C̄	log C	log C̄
1-26-62	-.270	-1.448	(-.585)	-1.761
2-2-62	-.651	-2.088	(-.387)	-1.824
2-9-62	-1.285	-2.863	(-.308)	-1.877
2-19-62	(-.529)	-2.254	(-.180)	-1.906˙
2-23-62	(-.268)	-2.020	(-.107)	-1.858
3-6-62	(-.148)	-1.794	(-.165)	-1.711
3-19-62	(-.084)	-1.913	(-.038)	-1.868
3-22-62	(-.204)	-1.937	(-.087)	-1.820

TABLE XV: 6 minute Squares on Uniform Backgrounds

N = 2,000

Date	log C	log C̄
12-22-61	(-.070)	-1.741
12-28-61	(-.420)	-1.804
1-5-62	-.497	-1.919
1-10-62	-.191	-2.015

TABLE XVI: 6 minute Squares on Black Squares of Checkerboard Backgrounds

N = 2,500

Date	Average Luminance		Border or Center Luminance f = 10.	
	log C	log C̄	log C	log C̄
12-22-61	(-.070)	-.466	-.310	-.883
12-28-61	(-.420)	-2.128	.716	-.992
1-2-62	-1.376	-3.222	.974	-.861
1-5-62	-.497	-2.476	1.085	-.894
1-10-62	-.191	-2.191	1.188	-.812

TABLE XVII: 8 minute Squares on Uniform Backgrounds

N = 2,500

Date	log C	log $\bar{C}$
11-21-61	-.066	-1.856
11-29-61	-.531	-2.048
12-19-61	(-.404)	-1.741
12-21-61	(-.076)	-1.770
1-6-62	-1.376	-2.252

TABLE XVIII: 8 minute Squares on Black Squares of Checkerboard Backgrounds

N = 2,500

Date	Average Luminance		Border Luminance f = .483		Center Luminance f = 10.	
	log C	log $\bar{C}$	log C	log $\bar{C}$	log C	log $\bar{C}$
11-21-61	-.039	-1.963	(-1.119)	-3.044	1.259	-.665
11-29-61	-.532	-2.404	(-.426)	-2.299	1.077	-.796
12-15-61	(-1.352)	-3.180	(-.280)	-2.096	.932	-.895
12-19-61	(-.404)	-2.121	(-.150)	-1.867	.704	-1.012
12-21-61	(-.076)	-.288	(-.035)	-.248	-.215	-.427

TABLE XIX: 4 minute Squares on Lines between Squares in Checkerboard Backgrounds

N = 4,000

Date	Average Luminance		Black Square Luminance f = 10		White Square Luminance f = .483	
	log C	log $\bar{C}$	log C	log $\bar{C}$	log C	log $\bar{C}$
5-15-62	-.140	-1.453	1.210	-.103	(-.777)	-2.090
5-17-62	-.363	-1.784	1.125	-.296	(-.512)	-1.934
5-18-62	-.838	-2.192	1.019	-.334	(-.350)	-1.704
5-22-62	(-.822)	-2.212	.874	-.517	(-.228)	-1.620
5-23-62	(-.365)	-1.852	.670	-.816	(-.139)	-1.626
5-24-62	(-.136)	-1.632	.230	-1.266	(-.060)	-1.556
5-25-62	(-.006)	-1.523	(-.070)	-1.588	(-.002)	-1.520
5-28-62	.006	-1.288	1.282	-.013	(-1.538)	-2.831

TABLE XX: 4 minute Squares on Lines between Squares in Checkerboard Backgrounds

N = 4,000

Date	Black Square Luminance	Contrast White Square Luminance	log Contrast Rendition
5-15-62	16.25	-.167	-1.313
5-17-62	13.34	-.307	-1.422
5-18-62	10.45	-.447	-1.354
5-22-62	7.49	-.591	-1.390
5-23-62	4.68	-.726	-1.487
5-24-62	1.70	-.870	-1.496
5-25-62	-.85	-.993	-1.517
5-28-62	19.1	-.029	-1.296

TABLE XXI: 4 minute Squares on Terrain Photo Backgrounds

N = 1,000

Date	Average Luminance log C	log $\bar{C}$	Border or Center Luminance log C	log $\bar{C}$
6-21-62	(-.503)	-1.915	(-.218)	-1.630
6-22-62	-.268	-1.835	.120	-1.447
6-25-62	-1.222	-3.020	-.224	-2.023
6-27-62	-1.328	-2.448	(-.402)	-1.522
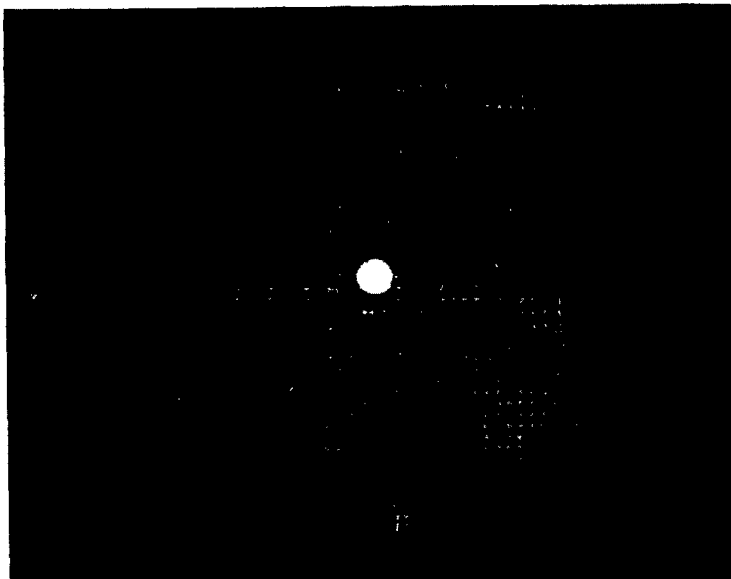
Fig. 1. 24 minute bright circular target on
Ball-bearing Board Background.
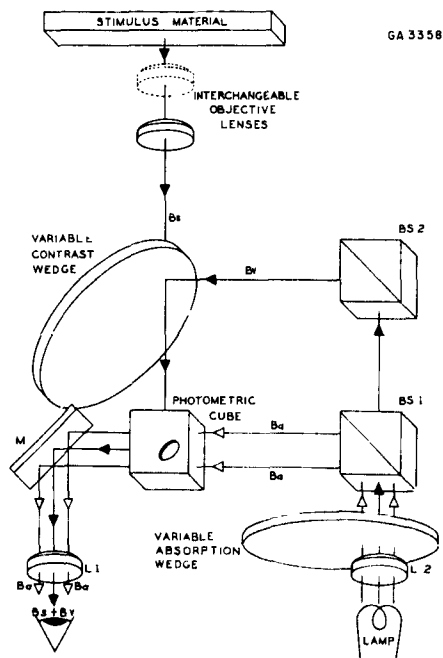
Fig. 2. Optical schematic drawing of contrast
reduction device used in the Method
of Adjustment experiments.
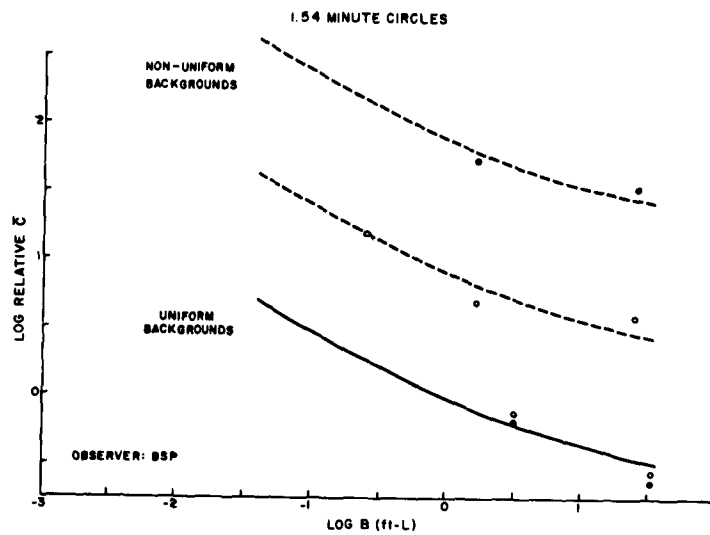
1.54 MINUTE CIRCLES

NON-UNIFORM
BACKGROUNDS

UNIFORM
BACKGROUNDS

OBSERVER: BSP

LOG RELATIVE C̄

LOG B (ft-L)

Fig. 3. Data from the Method of Adjustment experiments.
         Open circles: bright targets;   Filled circles:
         dark targets.

3.08 MINUTE CIRCLES

NON-UNIFORM
BACKGROUNDS

UNIFORM
BACKGROUNDS

OBSERVER: BSP

LOG RELATIVE C̄

LOG B (ft-L)
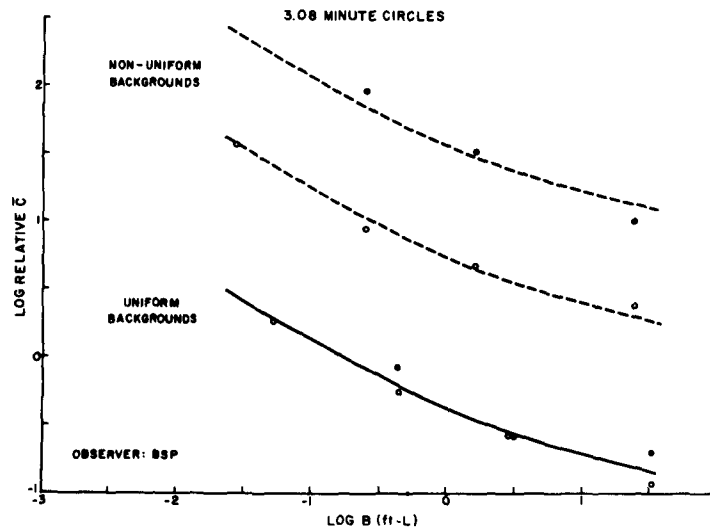
Fig. 4. Data from the Method of Adjustment experiments.
         Open circles: bright targets;   Filled circles:
         dark targets.
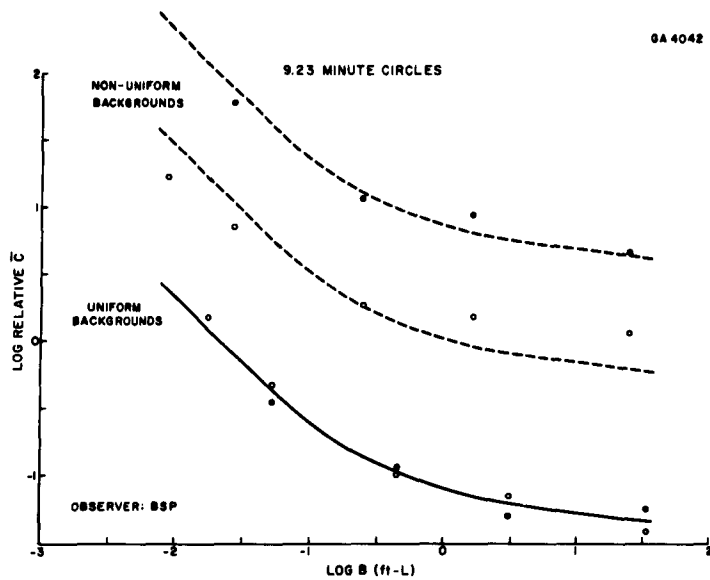
Fig. 5. Data from the Method of Adjustment experiments.
Open circles: bright targets; Filled circles:
dark targets.

Fig. 6. Data from the Method of Adjustment experiments.
Open circles: bright targets; Filled circles:
dark targets.

GA 4044

73.8 MINUTE CIRCLES

NON-UNIFORM
BACKGROUNDS

LOG RELATIVE C̃

UNIFORM
BACKGROUNDS

OBSERVER: SSP

LOG B (ft -L)

Fig. 7. Data from the Method of Adjustment experiments.
Open circles: bright targets; Filled circles:
dark targets.

GA 4037

4 MINUTE CIRCLES

NON-UNIFORM
BACKGROUNDS

LOG RELATIVE C̃

UNIFORM
BACKGROUNDS

OBSERVER: SSP

LOG B (ft-L)
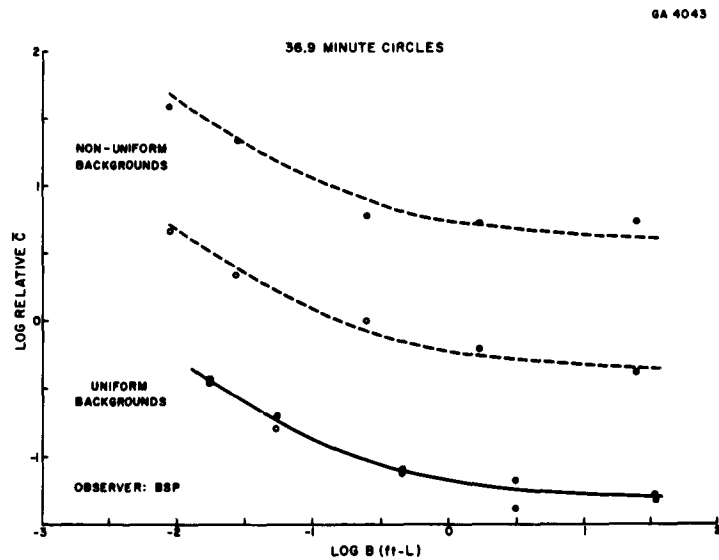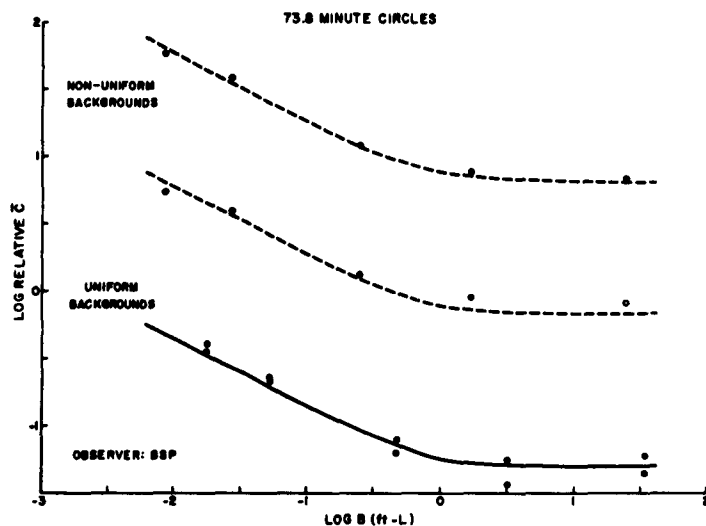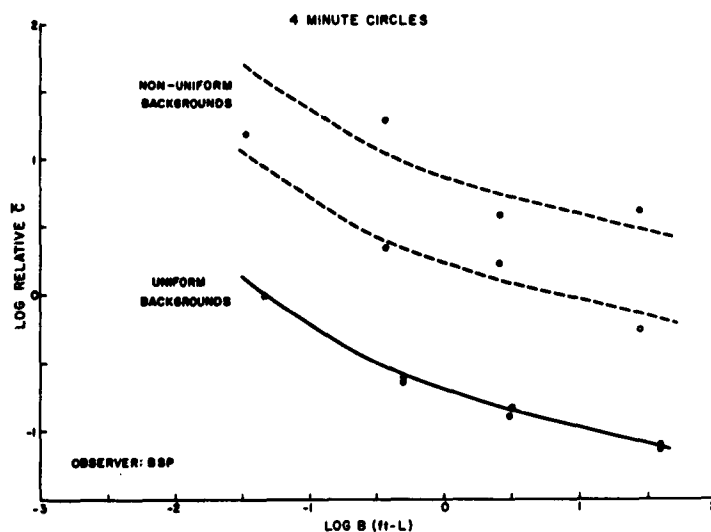
Fig. 8. Data from the Method of Adjustment experiments.
Open circles: bright targets; Filled circles:
dark targets.
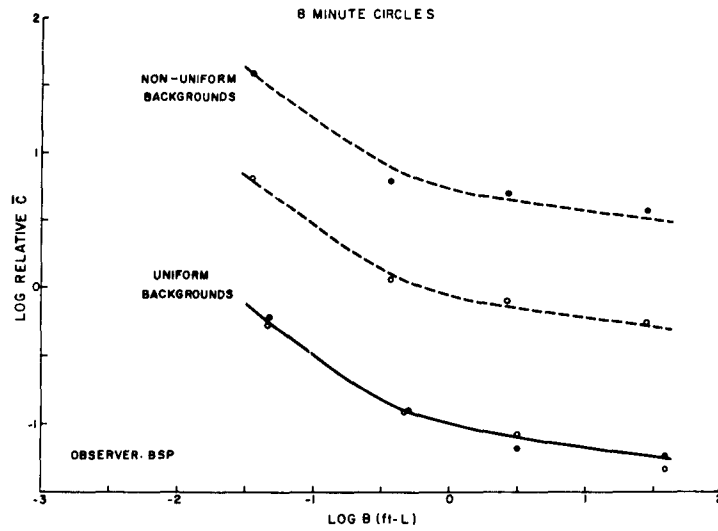
Fig. 9. Data from the Method of Adjustment experiments. Open circles: bright targets; Filled circles: dark targets.
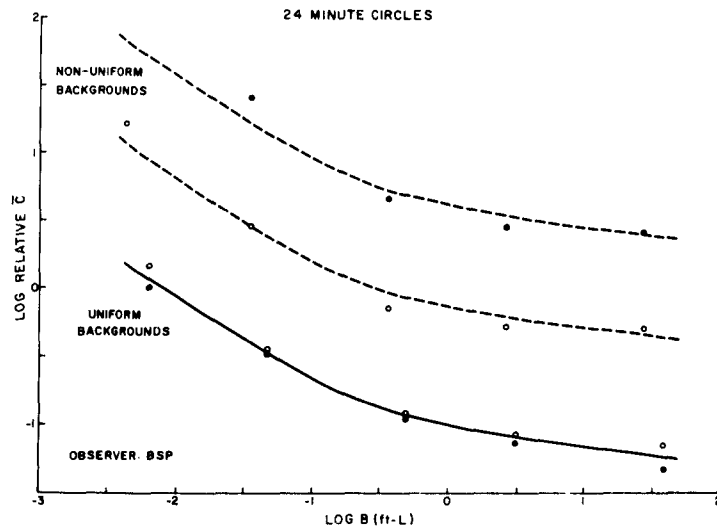
Fig. 10. Data from the Method of Adjustment experiments. Open circles: bright targets; Filled circles: dark targets.
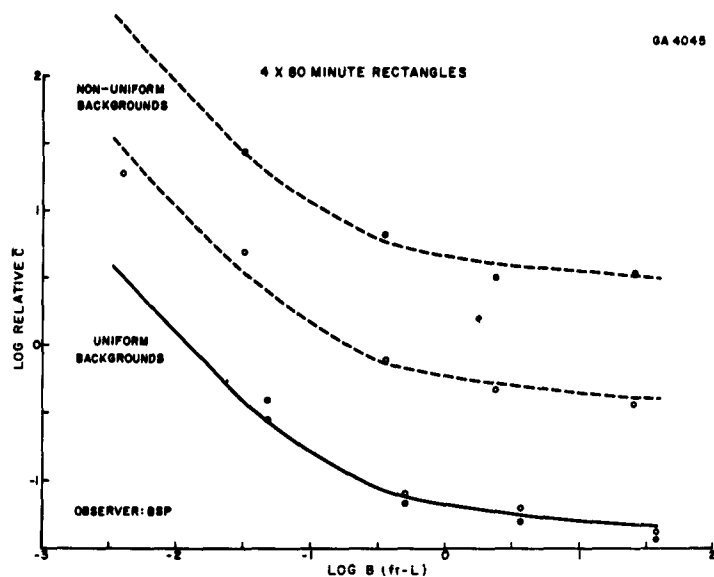
Fig. 11. Data from the Method of Adjustment experiments.
Open circles: bright targets; Filled circles:
dark targets.
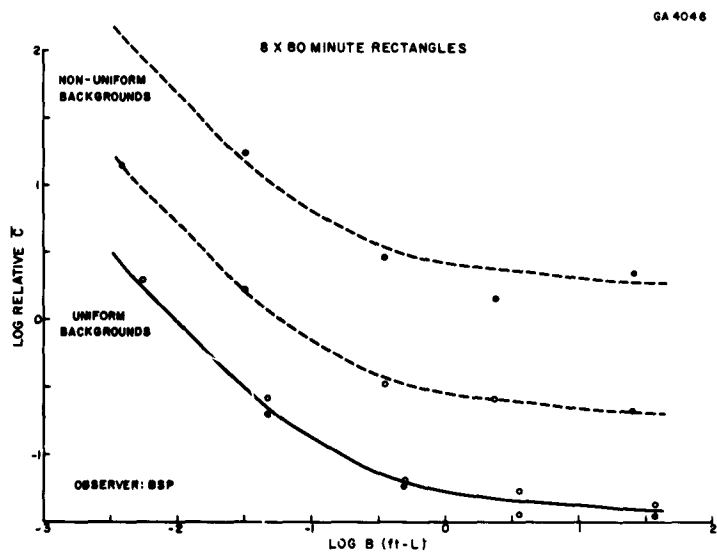
Fig. 12. Data from the Method of Adjustment experiments.
Open circles: bright targets; Filled circles:
dark targets.
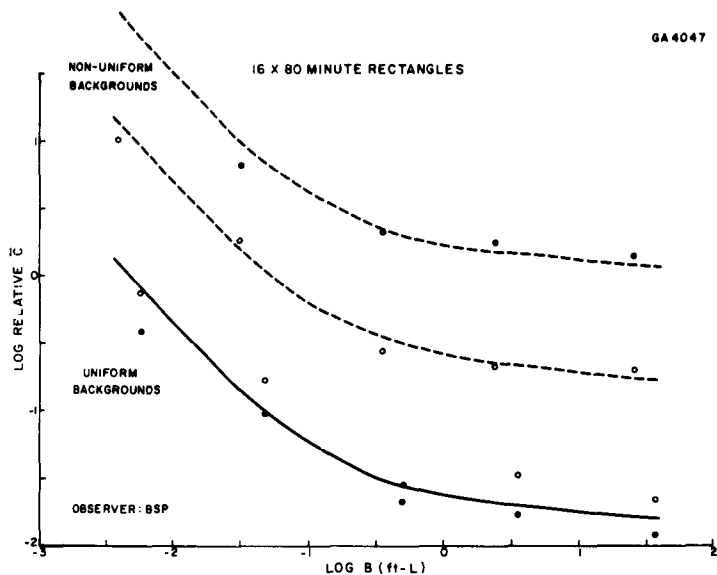
Fig. 13. Data from the Method of Adjustment experiments.
Open circles: bright targets; Filled circles:
dark targets.

Fig. 14. Data from the Method of Adjustment experiments.
Open circles: bright targets; Filled circles:
dark targets.
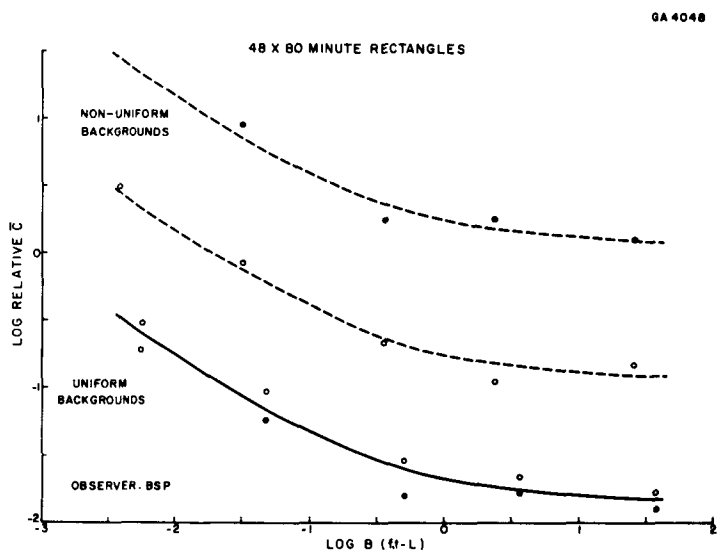
80 X 80 MINUTE RECTANGLES
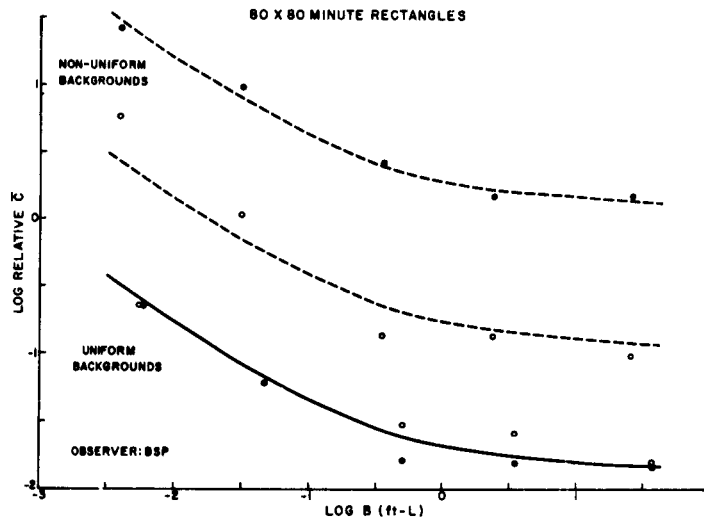
Fig. 15. Data from the Method of Adjustment experiments.
Open circles: bright targets; Filled circles:
dark targets.

GA 3372
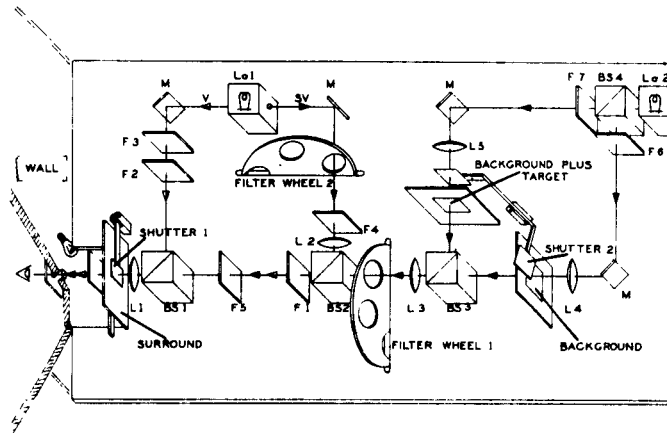
Fig. 16. Optical schematic drawing of contrast reduction
device used in Method of Constant Stimulus experi-
ments with photographic transparencies.
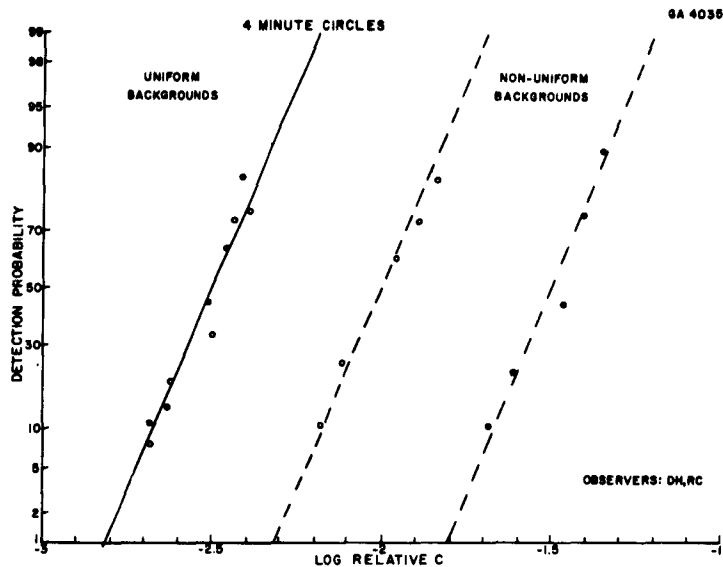
Fig. 17. Data from the Method of Constant Stimulus
experiments with photographic transparencies.
Open circles: bright targets; Filled circles:
dark targets.
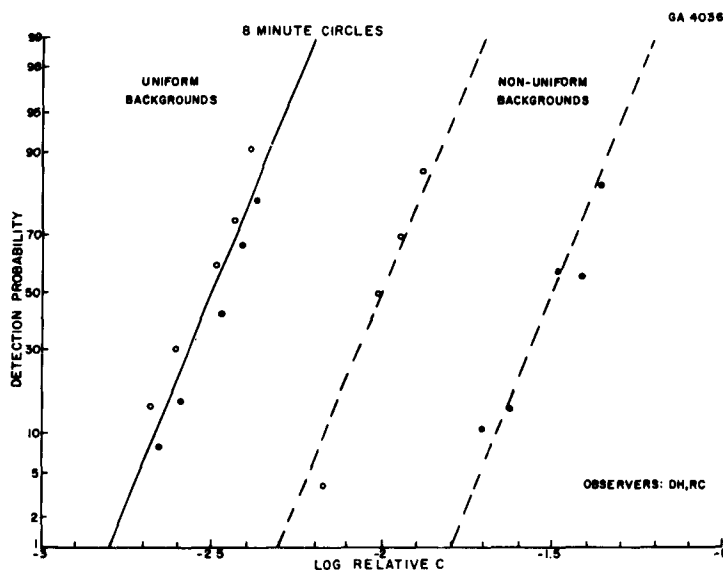
Fig. 18. Data from the Method of Constant Stimulus
experiments with photographic transparencies.
Open circles: bright targets; Filled circles:
dark targets.
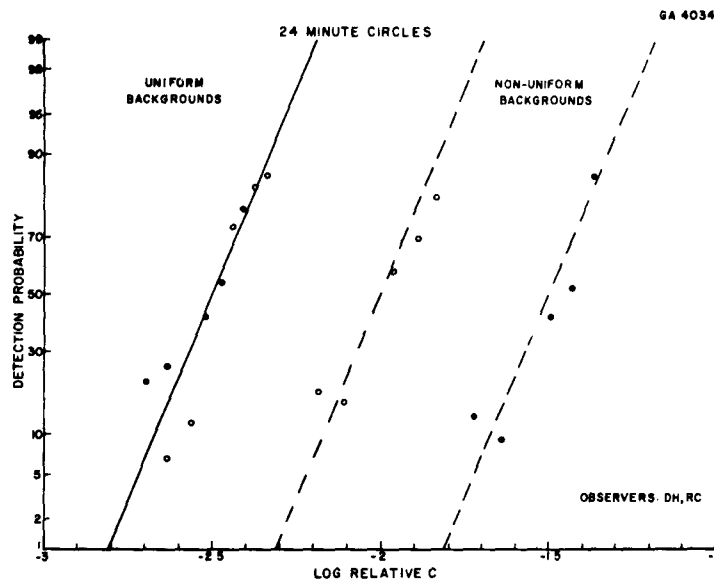
Fig. 19. Data from the Method of Constant Stimulus
experiments with photographic transparencies.
Open circles: bright targets; Filled circles:
dark targets.
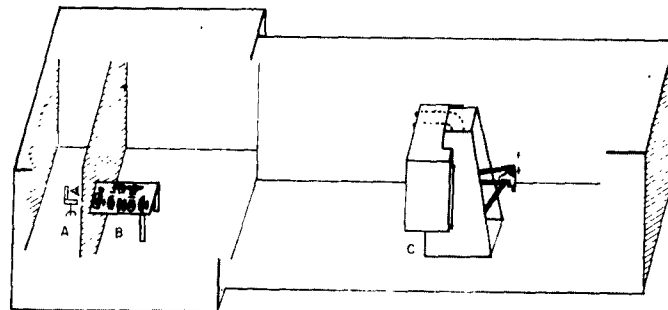
Fig. 20. Layout of equipment used in Method of Constant
Stimulus experiments with real backgrounds.
A. Observer Station; B. Contrast reduction
device; C. Target presentation equipment.
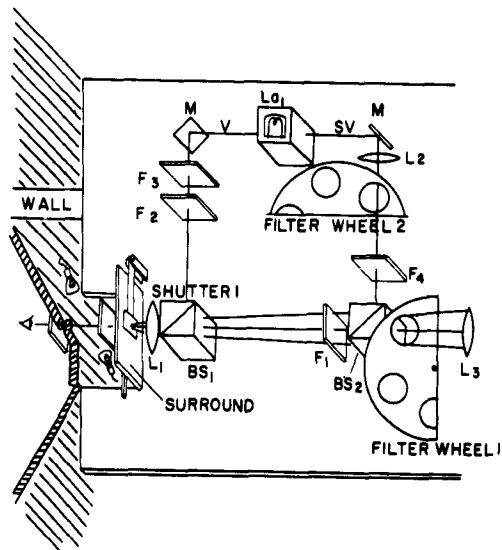
Fig. 21. Optical schematic drawing of contrast
reduction device used in Method of
Constant Stimulus experiments with
real backgrounds.
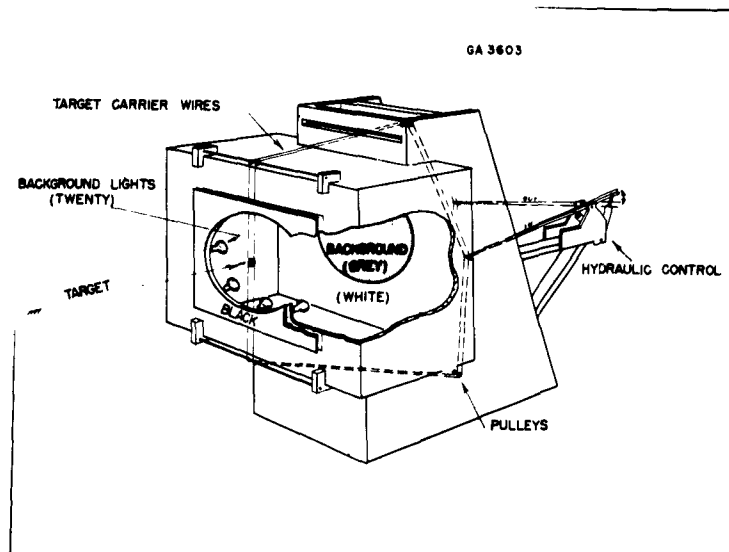
Fig. 22. Detail of the target presentation equipment.

GA 3609

4 MINUTE TARGET

24 MINUTE TARGET
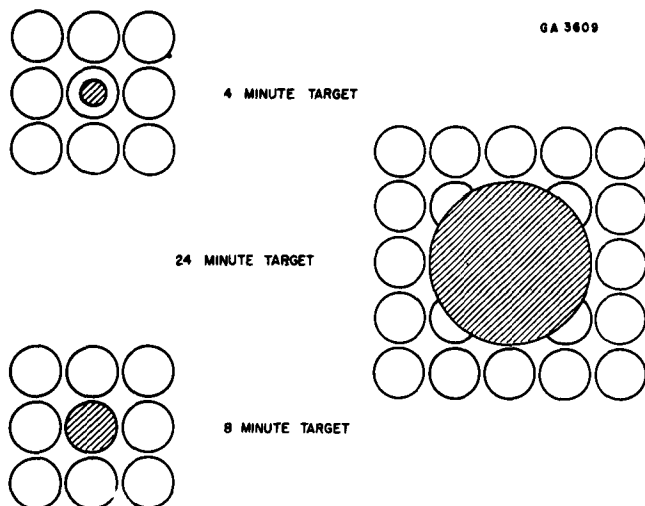
8 MINUTE TARGET

Fig. 23. Schematic drawing of target positions with
respect to elements of the Ball-bearing Board
Background.
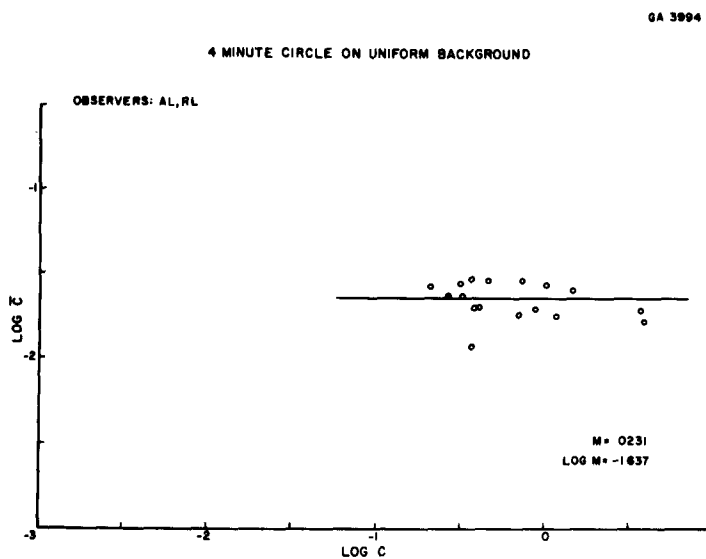
GA 3994

4 MINUTE CIRCLE ON UNIFORM BACKGROUND

OBSERVERS: AL,RL

LOG Z
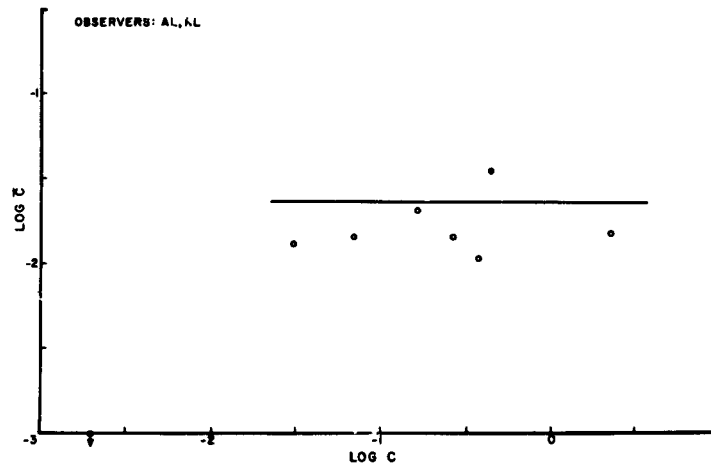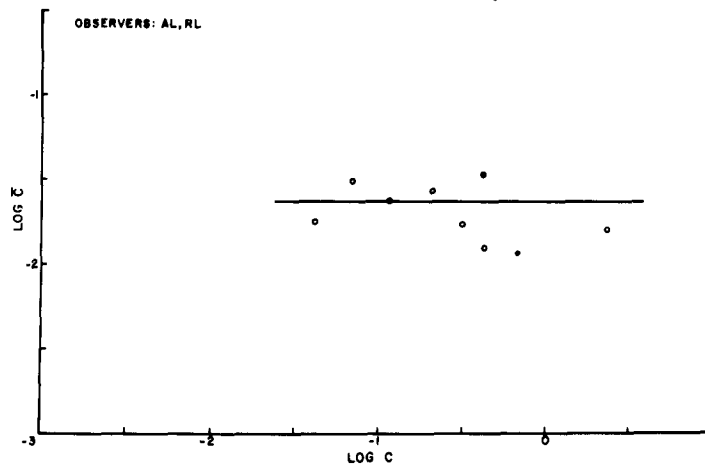
M = 0231
LOG M = -1637

LOG C

Fig. 24. Data from the Method of Constant Stimulus
experiments. Open circles: bright targets;
Filled circles: dark targets.

4 MINUTE CIRCLE CENTERED ON BALL-BEARING BOARD ELEMENT

AVERAGE LUMINANCE BASIS

OBSERVERS: AL, RL

LOG τ

LOG C

Fig. 25.   Data from the Method of Constant Stimulus
           experiments. Open circles: bright targets;
           Filled circles: dark targets.

GA 4001

8 MINUTE CIRCLE ON UNIFORM BACKGROUND

OBSERVERS: AL, RL

LOG τ

M = .0132

LOG M = -1.880

LOG C

Fig. 26.   Data from the Method of Constant Stimulus
           experiments. Bright targets only.

8 MINUTE CIRCLE CENTERED ON BALL-BEARING BOARD ELEMENT

AVERAGE LUMINANCE BASIS

OBSERVERS: AL, RL

LOG C̄

-1

-2

-3

-2   -1   0

LOG C
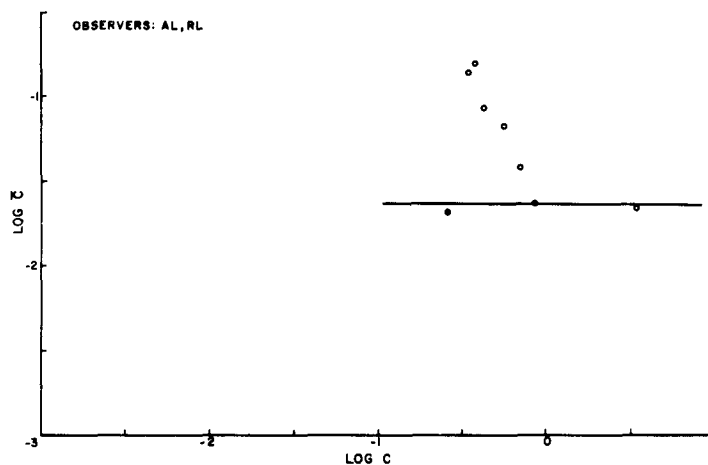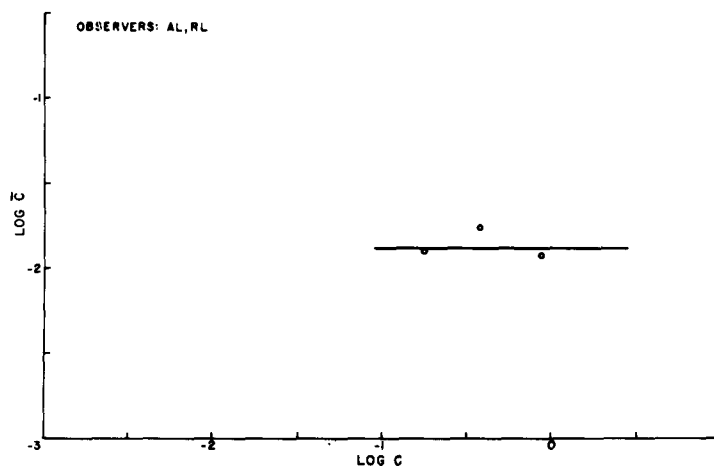
Fig. 27. Data from the Method of Constant Stimulus
experiments. Bright targets only.

24 MINUTE CIRCLE ON UNIFORM BACKGROUND

OBSERVERS: AL, RL

LOG C̄
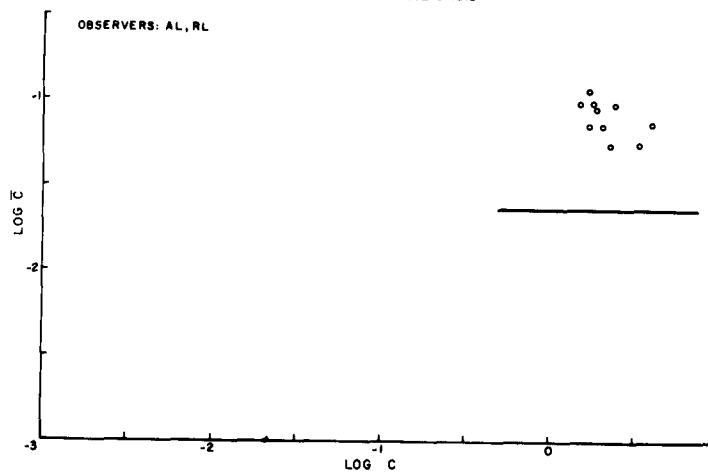
-1

-2

M = .00814
LOG M = -2.090

-3

-2   -1   0

LOG C
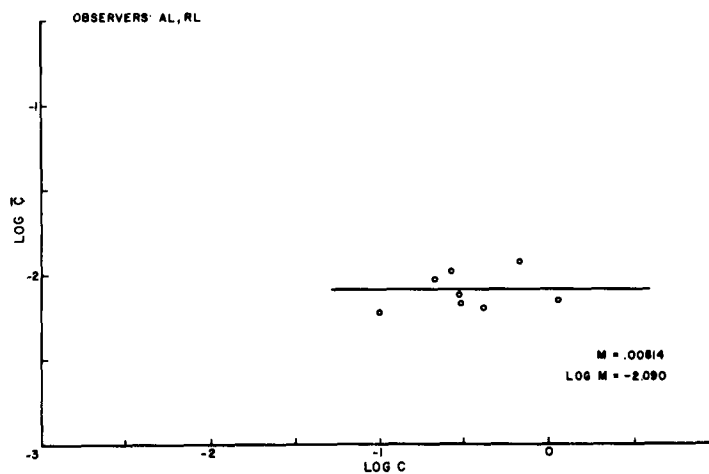
Fig. 28. Data from the Method of Constant Stimulus
experiments. Bright targets only.

24 MINUTE CIRCLE CENTERED ON BALL-BEARING BOARD ELEMENT

AVERAGE LUMINANCE BASIS

OBSERVERS· AL, RL

Fig. 29. Data from the Method of Constant Stimulus experiments. Bright targets only.

GA 4009

4 MINUTE CIRCLE CENTERED ON BALL-BEARING BOARD ELEMENT

AVERAGE LUMINANCE BASIS

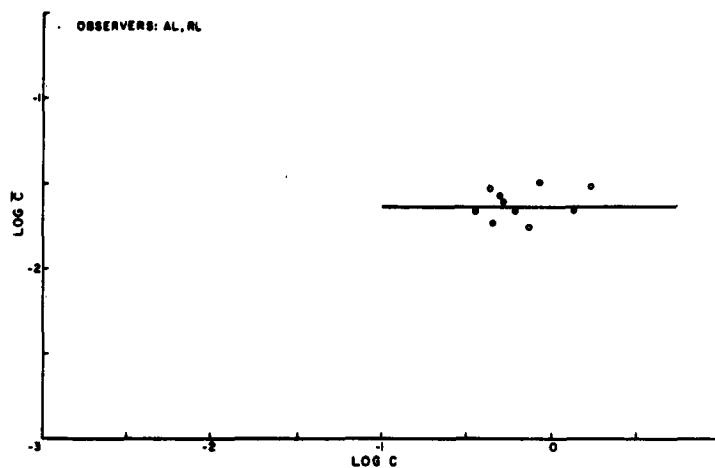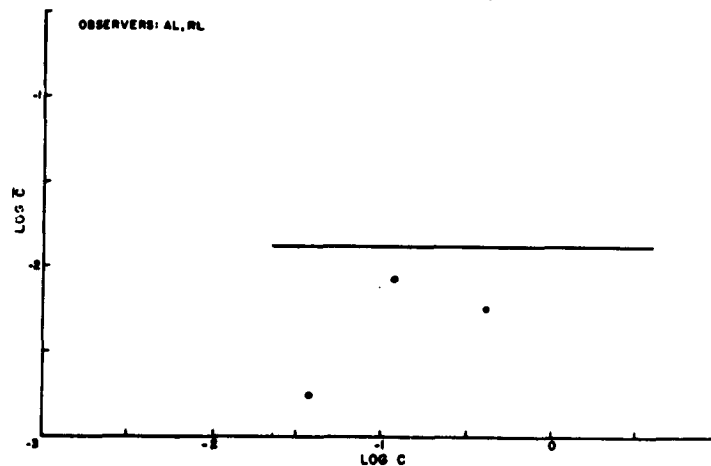OBSERVERS: AL, RL   0.1 SECOND EXPOSURE
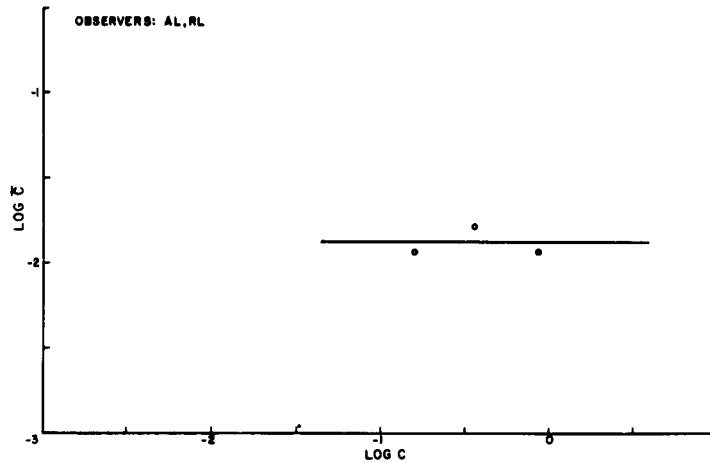

Fig. 30. Data from the Method of Constant Stimulus experiments. Bright targets only.

GA 4010

24 MINUTE CIRCLE CENTERED ON BALL-BEARING BOARD ELEMENT

AVERAGE LUMINANCE BASIS

OBSERVERS: AL, RL   0.1 SECOND EXPOSURE
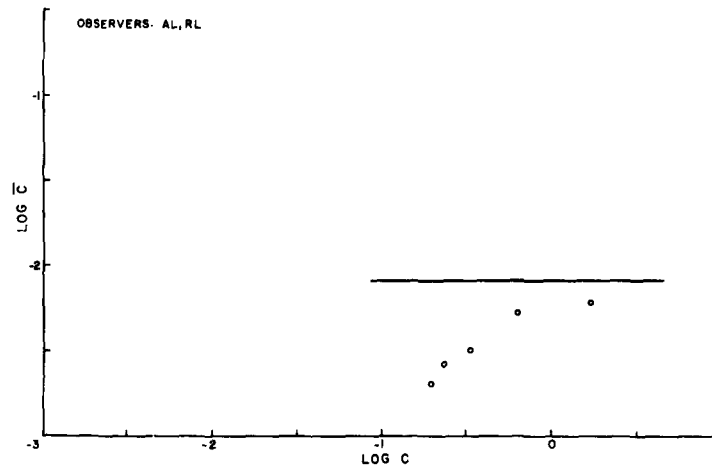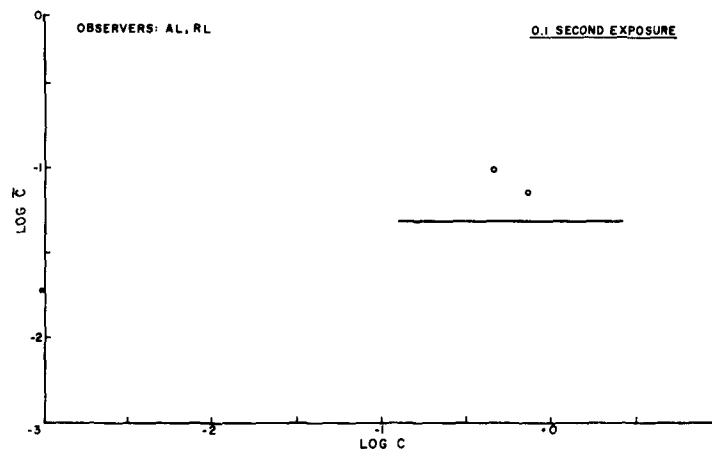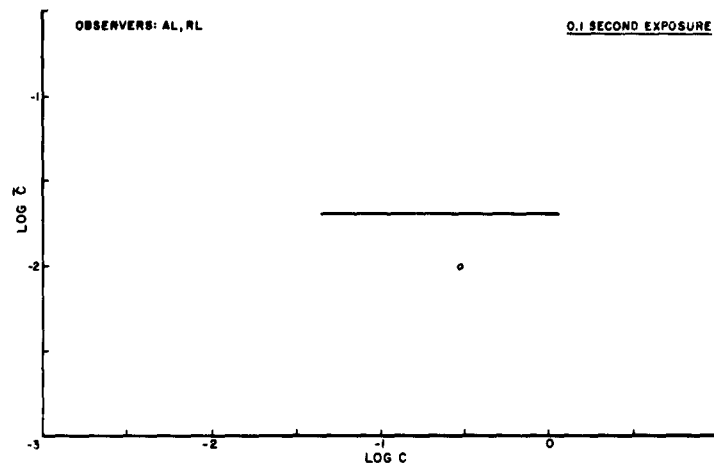
Fig. 31.   Data from the Method of Constant Stimulus
experiments. Bright target.
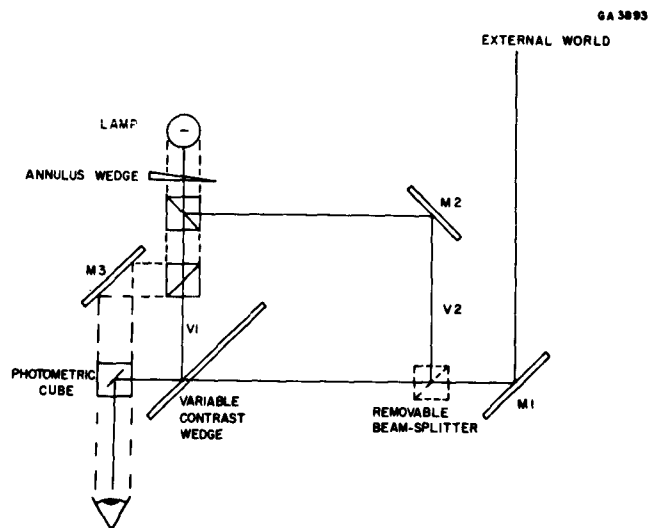
Fig. 32.   Optical schematic drawing of the Visual
Task Evaluator.
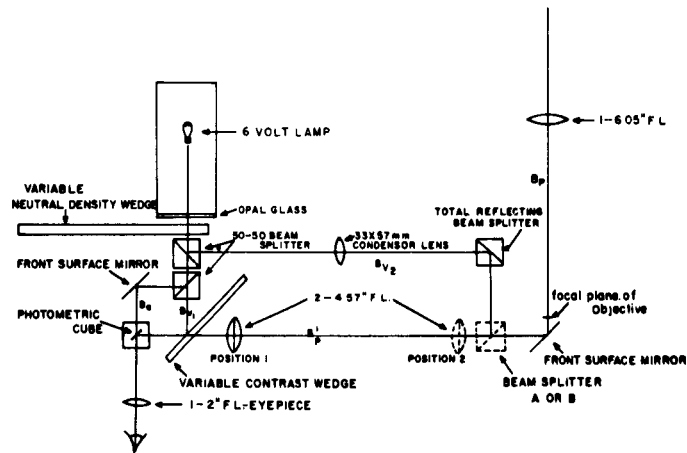
Fig. 33. Layout of optical components of the Visual Task Evaluator.
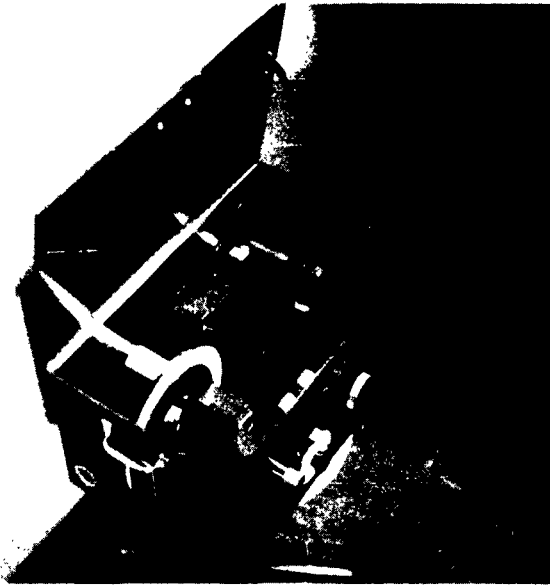
Fig. 34. Photograph of the Visual Task Evaluator.

GA 3882
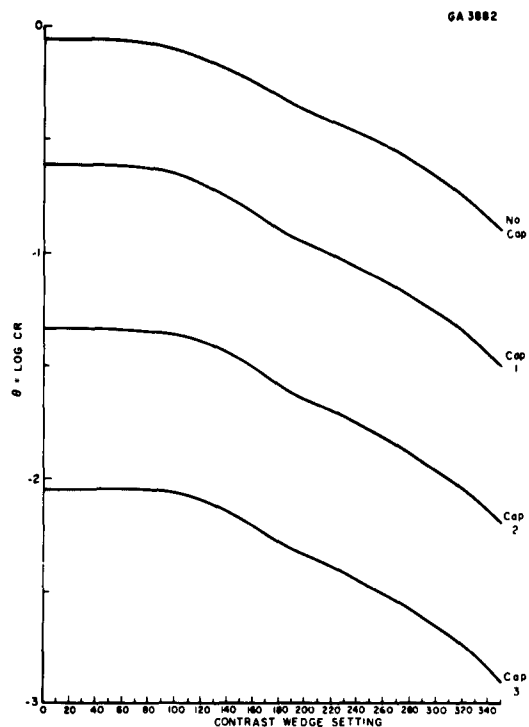
Fig. 35. Calibration data on the
contrast rendition of
the Visual Task Evaluator.

GA 3883
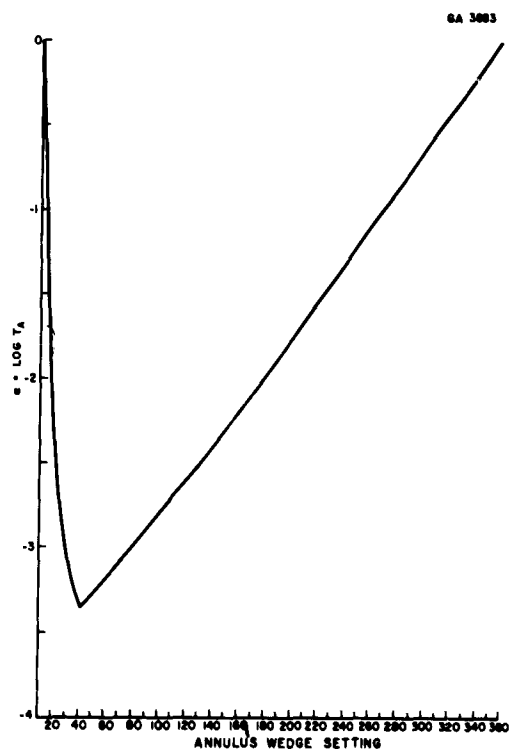
Fig. 36. Calibration data on the
transmittance of the
neutral annulus wedge
of the Visual Task
Evaluator.
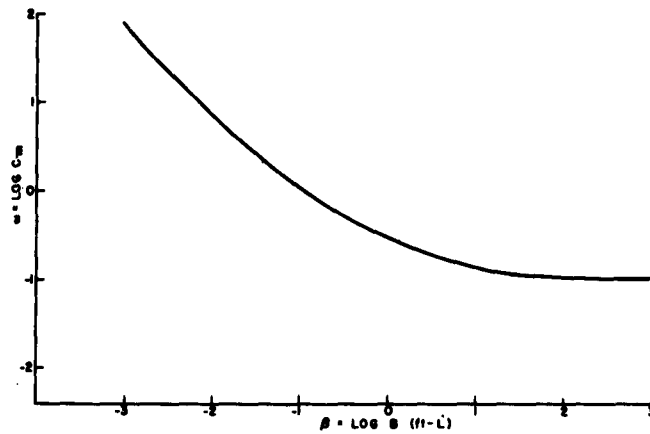
Fig. 37. Calibration data of the threshold contrast-luminance function of the operator of the Visual Task Evaluator.

VALIDATION OF THE VISUAL TASK EVALUATOR
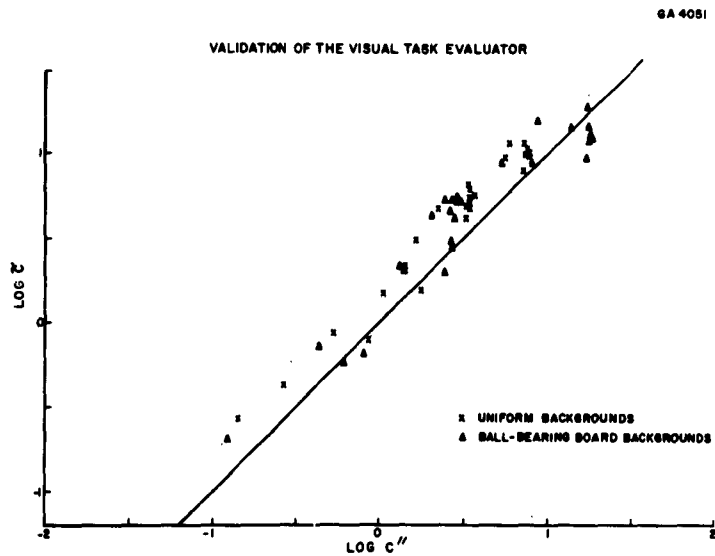
Fig. 38. Experimental data of the validation study of the Visual Task Evaluator.

4 MINUTE CIRCLE CENTERED BETWEEN BALL-BEARING BOARD ELEMENTS

AVERAGE LUMINANCE BASIS
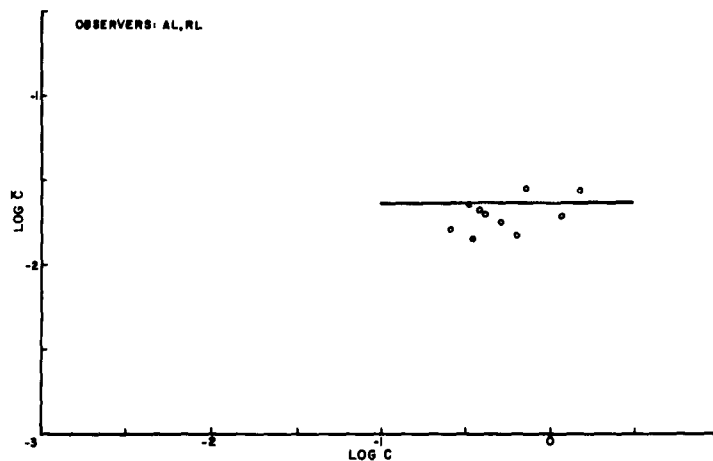
Fig. 39. Data from the Method of Constant Stimulus
experiments. Bright targets only.

GA 4015
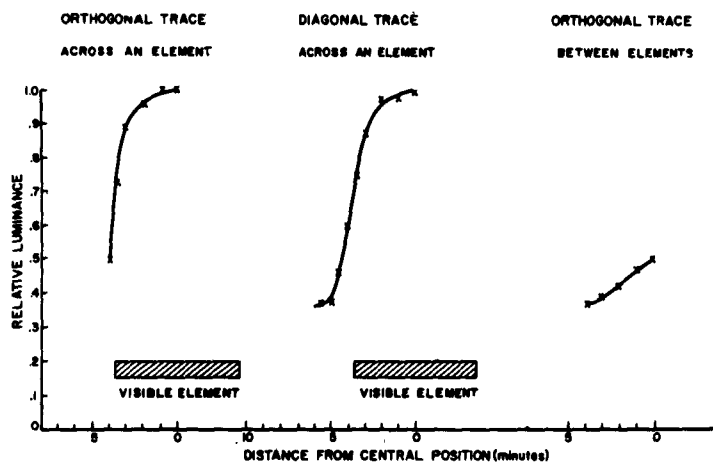
Fig. 40. Point-to-point luminance data on the Ball-
bearing Board Background.

ORTHOGONAL TRACE ACROSS ELEMENTS

24 MINUTE

8 MINUTE

4 MINUTE

RELATIVE LUMINANCE

← C 4,8,24

←8 4

←B 8

←8 24

VISIBLE ELEMENT

DISTANCE FROM ELEMENT CENTER (minutes)
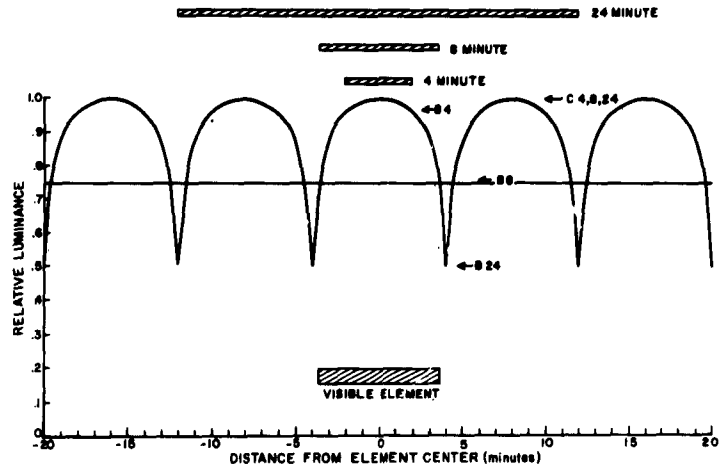
Fig. 41. Luminance cross-section of Ball-bearing Board Background showing the locations of centered targets.

DIAGONAL TRACE ACROSS ELEMENTS

4 MINUTE

RELATIVE LUMINANCE

←B 4

←C 4

VISIBLE ELEMENT

DISTANCE FROM ELEMENT CENTER (minutes)
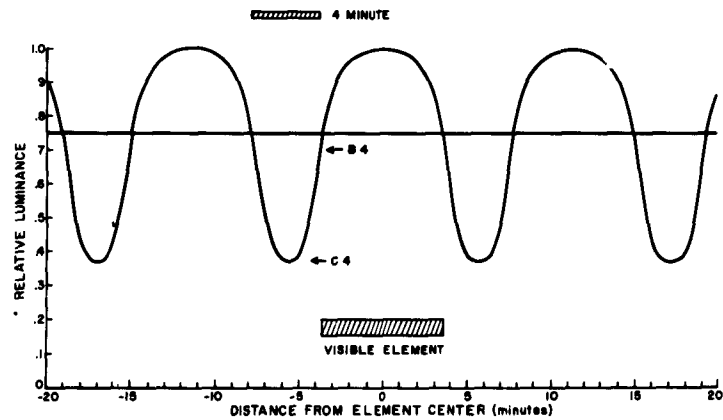
Fig. 42. Luminance cross-section of Ball-bearing Board Background showing the location of the 4 minute target centered between the elements.

ORTHOGONAL TRACE BETWEEN ELEMENTS
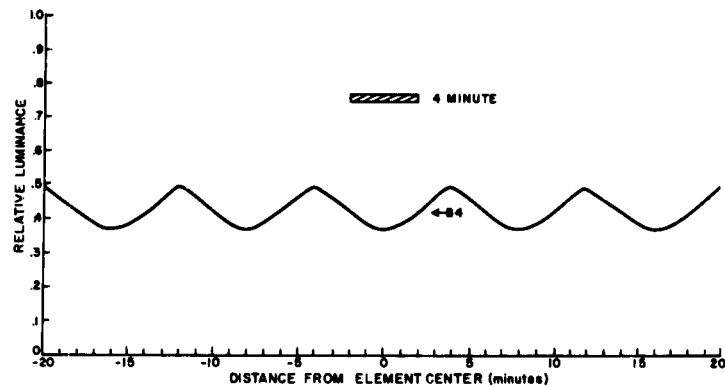
Fig. 43. Luminance cross-section of Ball-bearing Board
Background showing the location of the 4 minute
target centered between the elements.

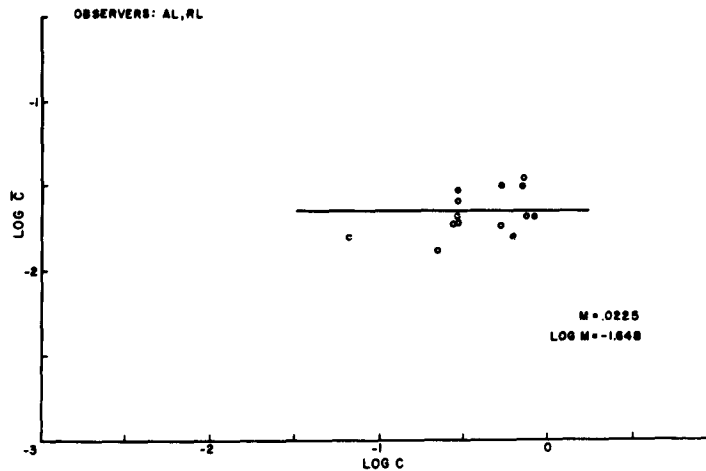4 MINUTE CIRCLE CENTERED ON BALL-BEARING BOARD ELEMENT

CENTER LUMINANCE BASIS

Fig. 44. Data from the Method of Constant Stimulus
experiments. Open circles: bright targets,
Filled circles: dark targets.

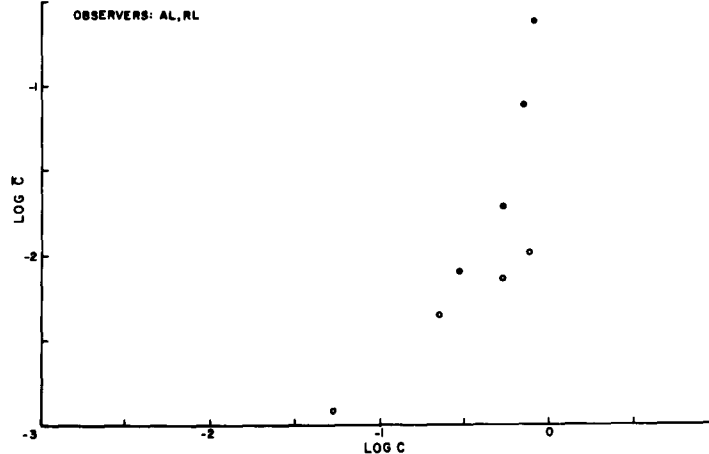4 MINUTE CIRCLE CENTERED ON BALL-BEARING BOARD ELEMENT

BORDER LUMINANCE BASIS

OBSERVERS: AL,RL

Fig. 45. Data from the Method of Constant Stimulus
experiments. Open circles: bright targets
Filled circles: dark targets.

4 MINUTE CIRCLE CENTERED BETWEEN BALL-BEARING BOARD ELEMENTS

CENTER LUMINANCE BASIS

OBSERVERS: AL,RL

Fig. 46. Data from the Method of Constant Stimulus
experiments. Bright targets only.

4 MINUTE CIRCLE CENTERED BETWEEN BALL-BEARING BOARD ELEMENTS

BORDER LUMINANCE BASIS

OBSERVERS: AL, RL

Fig. 47. Data from the Method of Constant Stimulus experiments. Bright targets only.

8 MINUTE CIRCLE CENTERED ON BALL-BEARING BOARD ELEMENTS

CENTER LUMINANCE BASIS

OBSERVERS: AL, RL

Fig. 48. Data from the Method of Constant Stimulus experiments. Bright targets only.

8 MINUTE CIRCLE CENTERED ON BALL-BEARING BOARD ELEMENT

BORDER LUMINANCE BASIS

OBSERVERS: AL,RL

LOG C̄

LOG C

Fig. 49. Data from the Method of Constant Stimulus
experiments. Bright targets only.

GA 4008

24 MINUTE CIRCLE CENTERED ON BALL-BEARING BOARD ELEMENT
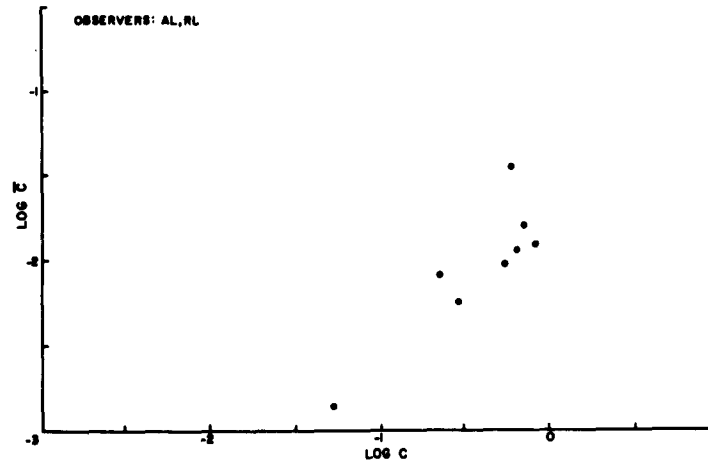
CENTER LUMINANCE BASIS

OBSERVERS: AL, RL

LOG

LOG C
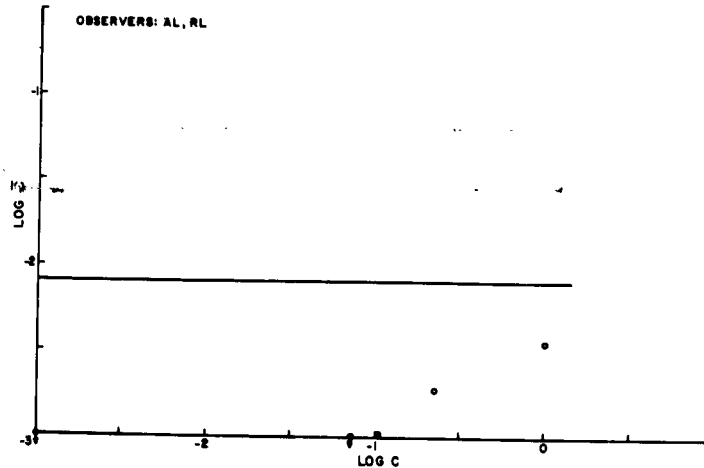
Fig. 50. Data from the Method of Constant Stimulus
experiments. Open circles: bright targets;
Filled circles: dark targets.

24 MINUTE CIRCLE CENTERED ON BALL-BEARING BOARD ELEMENT

BORDER LUMINANCE BASIS

OBSERVERS: AL, RL

LOG C̄

LOG C
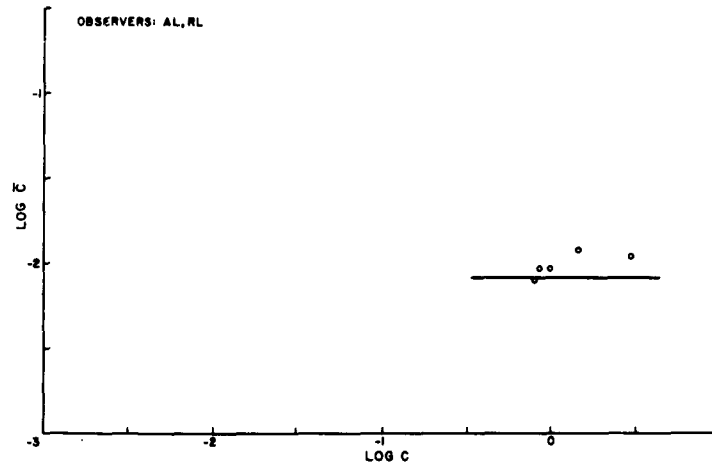
Fig. 51. Data from the Method of Constant Stimulus
experiments. Bright targets only.

GA 4011

EFFECT OF TARGET AREA

BALL-BEARING BOARD EXPERIMENT

x UNIFORM BACKGROUND
▲ BALL-BEARING BOARD BACKGROUND
(BORDER LUMINANCE BASIS)

LOG DIAMETER (minutes)

LOG C̄
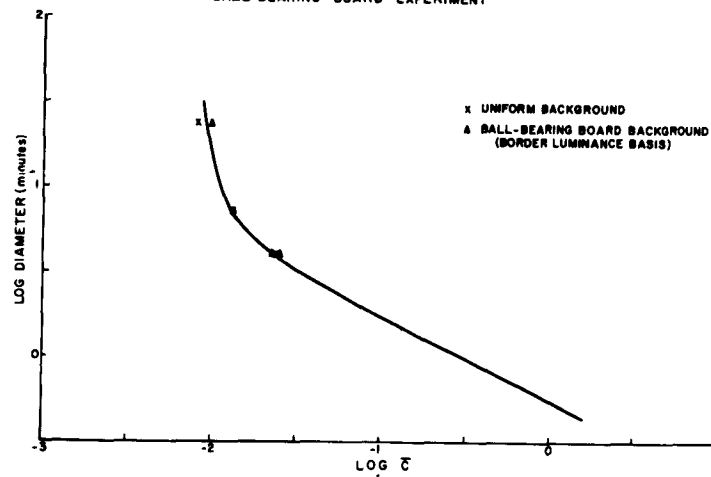
Fig. 52. Data from the Method of Constant Stimulus
experiments.

4 MINUTE SQUARE ON UNIFORM BACKGROUND

OBSERVERS: AL,RL

M = .0225
LOG M = -1.648

Fig. 53. Data from the Method of Constant Stimulus
experiments. Open circles: bright targets;
Filled circles: dark targets.

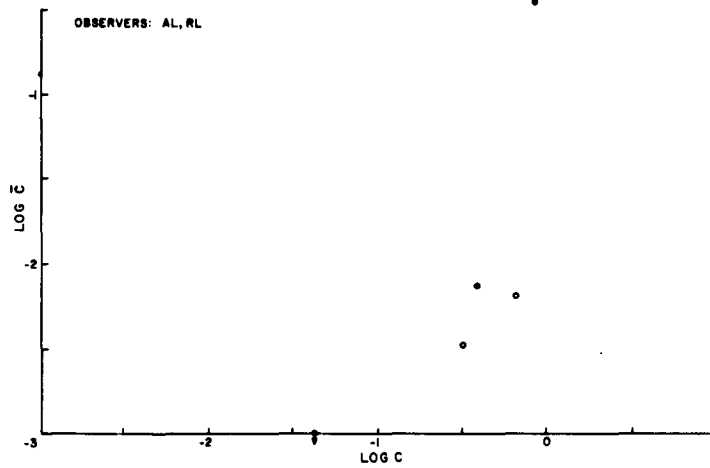4 MINUTE SQUARE ON BLACK SQUARE OF CHECKERBOARD BACKGROUND

AVERAGE LUMINANCE BASIS

OBSERVERS: AL,RL

Fig. 54. Data from the Method of Constant Stimulus
experiments. Open circles: bright targets;
Filled circles: dark targets.

4 MINUTE SQUARE ON BLACK SQUARE OF CHECKERBOARD BACKBOARD
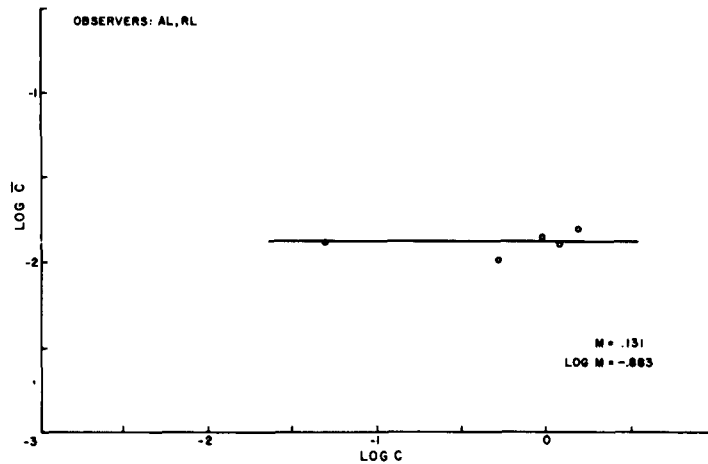
BORDER LUMINANCE OR CENTER LUMINANCE BASIS

OBSERVERS: AL, RL

M = .196

LOG M = -.708
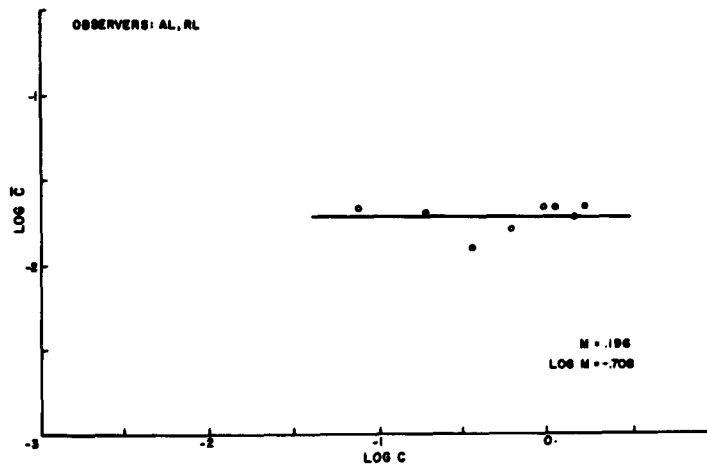
Fig. 55. Data from the Method of Constant Stimulus
experiments. Bright targets only.

6A 4019

4 MINUTE SQUARE ON WHITE SQUARE OF CHECKERBOARD BACKGROUND

AVERAGE LUMINANCE BASIS

OBSERVERS: AL, RL

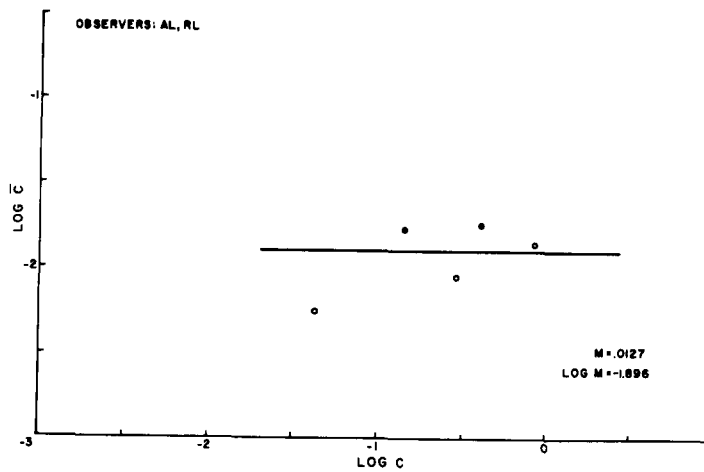Fig. 56. Data from the Method of Constant Stimulus
experiments. Open circles: bright targets;
Filled circles: dark targets.

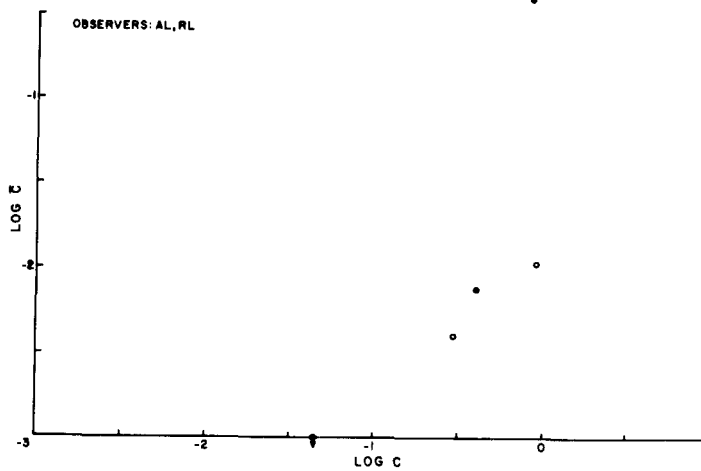4 MINUTE SQUARE ON WHITE SQUARE OF CHECKERBOARD BACKGROUND

BORDER LUMINANCE OR CENTER LUMINANCE BASIS

OBSERVERS: AL,RL

M = .0150
LOG M = -1.824

LOG C
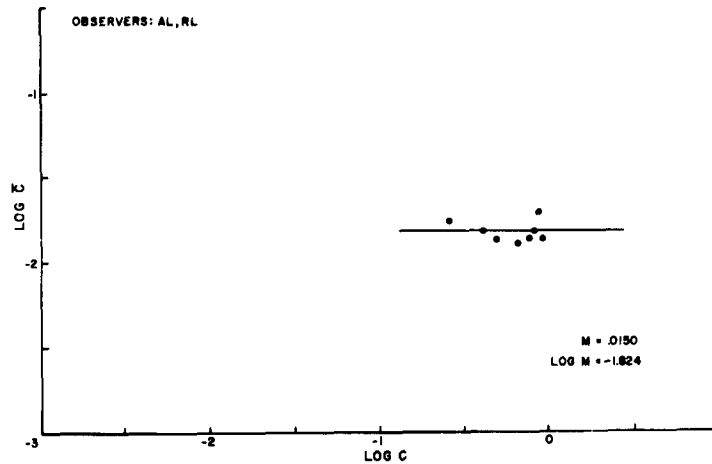
Fig. 57. Data from the Method of Constant Stimulus experiments. Dark targets only.

6 MINUTE SQUARE ON UNIFORM BACKGROUND
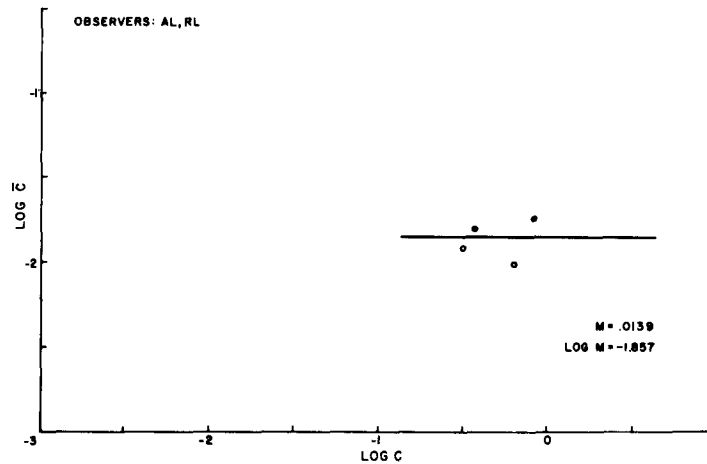
OBSERVERS: AL,RL

M = .0139
LOG M = -1.857

LOG C

Fig. 58. Data from the Method of Constant Stimulus experiments. Open circles: bright targets; Filled circles: dark targets.

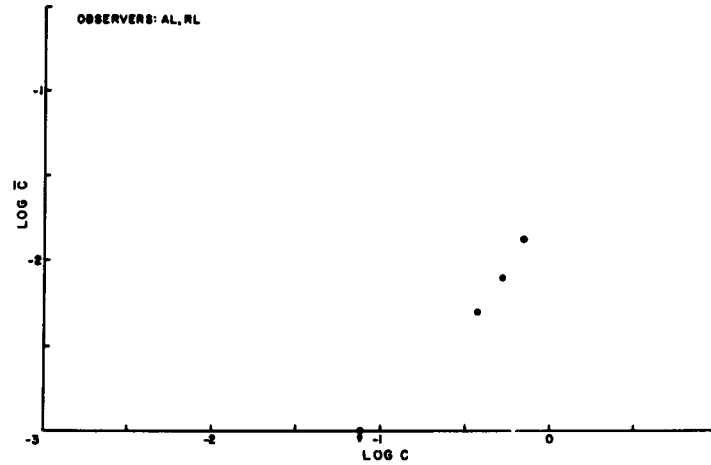6 MINUTE SQUARE ON BLACK SQUARE OF CHECKERBOARD BACKGROUND

AVERAGE LUMINANCE BASIS

OBSERVERS: AL, RL

LOG $\bar{C}$

LOG C

Fig. 59. Data from the Method of Constant Stimulus
experiments. Open circles: bright targets;
Filled circles: dark targets.

6 MINUTE SQUARE ON BLACK SQUARE OF CHECKERBOARD BACKGROUND

BORDER LUMINANCE OR CENTER LUMINANCE BASIS

OBSERVERS: AL, RL

LOG $\bar{C}$

M = .131
LOG M = -.883

LOG C

Fig. 60. Data from the Method of Constant Stimulus
experiments. Bright targets only.

8 MINUTE SQUARE ON UNIFORM BACKGROUND
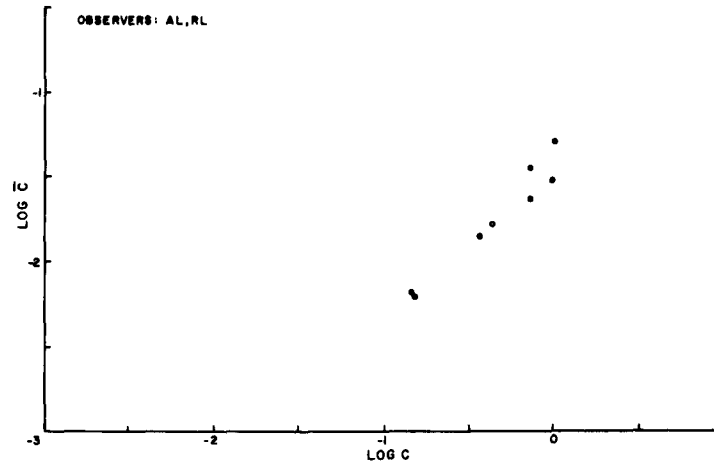
OBSERVERS: AL, RL

LOG C̄

M = .0127
LOG M = -1.896

LOG C

Fig. 61. Data from the Method of Constant Stimulus
experiments. Open circles: bright targets;
Filled circles: dark targets.

8 MINUTE SQUARE ON BLACK SQUARE OF CHECKERBOARD BACKGROUND
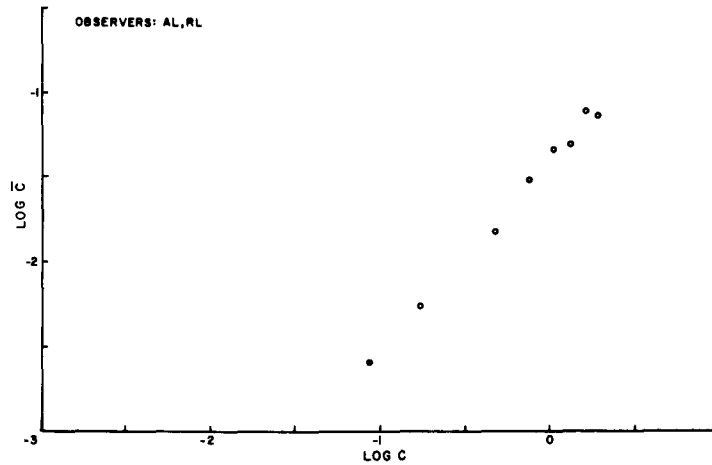AVERAGE LUMINANCE BASIS

OBSERVERS: AL, RL

LOG C̄

LOG C

Fig. 62. Data from the Method of Constant Stimulus
experiments. Open circles: bright targets;
Filled circles: dark targets.

8 MINUTE SQUARE ON BLACK SQUARE OF CHECKERBOARD BACKGROUND

BORDER LUMINANCE BASIS

OBSERVERS: AL, RL

LOG C̄

LOG C

Fig. 63. Data from the Method of Constant Stimulus
experiments. Dark targets only.

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8 MINUTE SQUARE ON BLACK SQUARE OF CHECKERBOARD BACKGROUND

CENTER LUMINANCE BASIS

OBSERVERS: AL, RL

LOG C̄

M=.195
LOG M=-.710

LOG C
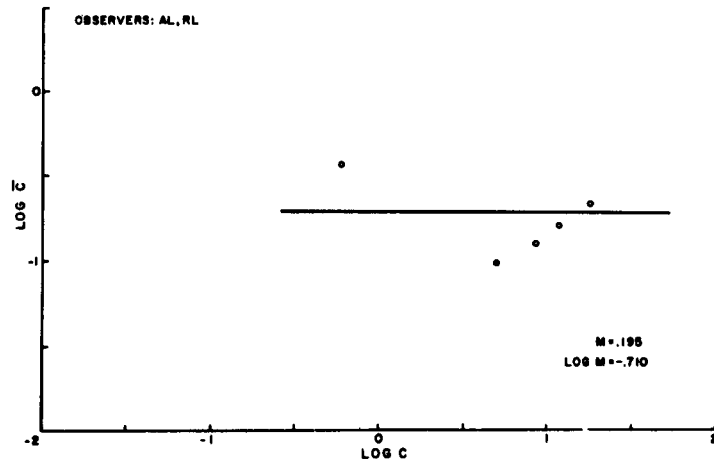
Fig. 64. Data from the Method of Constant Stimulus
experiments. Bright targets only.

4 MINUTE SQUARE ON LINE BETWEEN SQUARES IN CHECKERBOARD BACKGROUND

AVERAGE LUMINANCE BASIS

OBSERVERS: AL,RL

Fig. 65. Data from the Method of Constant Stimulus
experiments. Open circles: bright targets;
Filled circles: dark targets.

4 MINUTE SQUARE ON LINE BETWEEN SQUARES IN CHECKERBOARD BACKGROUND
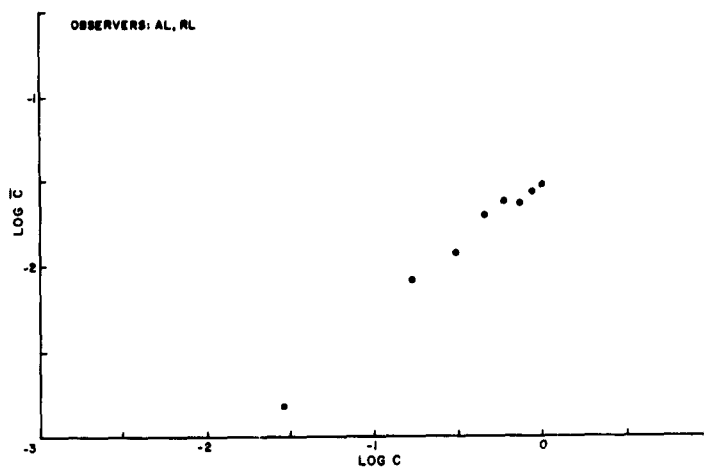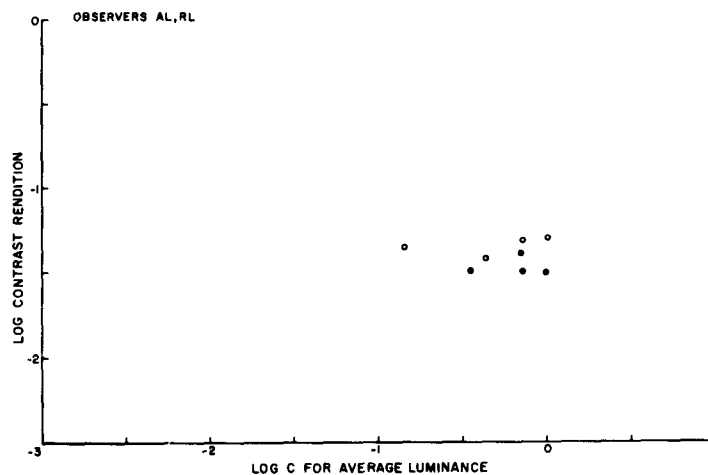
BLACK SQUARE LUMINANCE BASIS

OBSERVERS: AL,RL

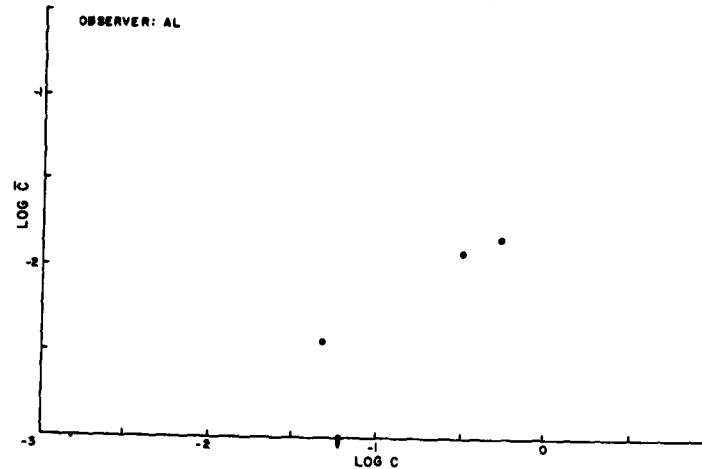Fig. 66. Data from the Method of Constant Stimulus
experiments. Open circles: bright targets;
Filled circles: dark targets.

4 MINUTE SQUARE ON LINE BETWEEN SQUARES IN CHECKERBOARD BACKGROUND

WHITE SQUARE LUMINANCE BASIS

OBSERVERS: AL, RL

Fig. 67. Data from the Method of Constant Stimulus experiments. Dark targets only.

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4 MINUTE SQUARE ON LINE BETWEEN SQUARES IN CHECKERBOARD BACKGROUND

OBSERVERS AL, RL

LOG CONTRAST RENDITION

LOG C FOR AVERAGE LUMINANCE

Fig. 68. Data from the Method of Constant Stimulus experiments. Open circles: bright targets; Filled circles: dark targets.

Fig. 69.   Aerial terrain photograph with 4 minute
           square target.

Fig. 70.   Aerial terrain photograph with 4 minute
           square target.

Fig. 71. Data from the Method of Constant Stimulus experiments. Open circles: bright targets; Filled circles: dark targets.
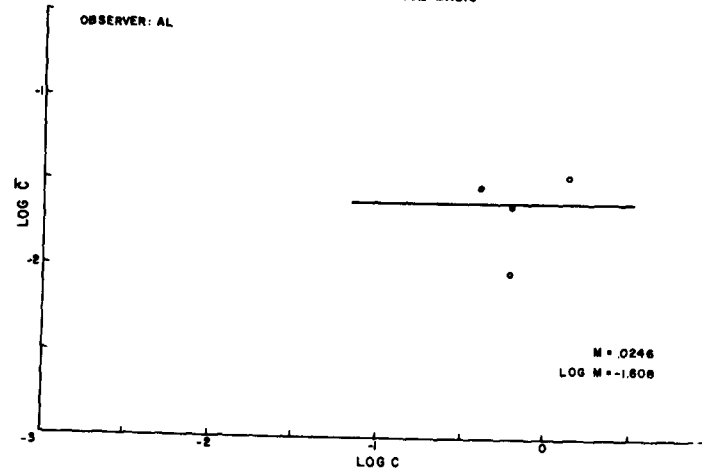

Fig. 72. Data from the Method of Constant Stimulus experiments. Open circles: bright targets; Filled circles: dark targets.
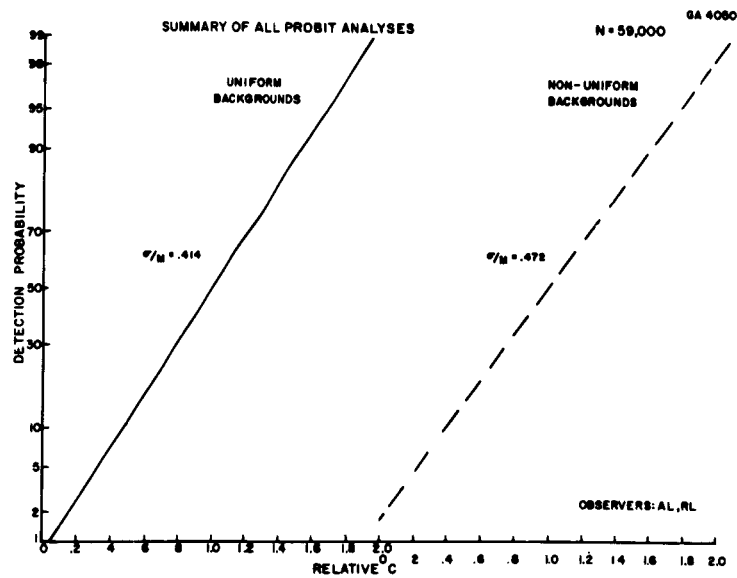
Fig. 73. Average normal ogives for backgrounds of uniform and non-uniform luminance plotted on probability grids.